HISTORIC DOMES IN THE MIDDLE EAST AND CENTRAL ASIA: A STUDY ON POINTED DISCONTINUOUS DOUBLE-SHELL DOMES

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ABSTRACT

This Research presents a developed geometric approach for deriving the typologies and geometries of discontinuous double-shell domes, specially pointed types, in Islamic architecture. In addition, common morphological and typological characteristics of Eastern domes are put forward. Firstly, an outline of the origin and development of Eastern domes are addressed since the early through to the late Islamic periods. Common formal architectural language of Eastern domes are established by estimation of 53 samples of domes amongst eight countries; these are Iran, Iraq, Afghanistan, Pakistan, Kazakhstan, Uzbekistan, and Turkmenistan, and Turkey.

In this regard, multifold approaches for analyzing those samples are organized into two certain parts. Besides, using *al-Kashi* geometrical features, a four-centered profile as an initial shape is constructed based on new geometric parameters to deduce the geometric commonalities of the two aspects of formal language (typologies and geometries) of such domes. Common geometric prototypes for typical profile shared by the study cases are generated and formulated according to a proposed system.

The theoretical frame work for the formal language of eastern domes, especially, pointed discontinuous double-shell domes is structured to indicate a moderate development of this sort of Islamic domes and highlight the specific geometric relationship between the Islamic dome configurations and practical mathematic rules for many decades. It can also be established firstly, a basic approach for considering the geometric compositional designs and typological derivations of the other Eastern domes and secondly may a basis for an approach in treating such historic structures in historic conservation programs.

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ABBREVIATIONS

FEM	Final Element Mesh Modeling
FEA	Finite Element Analysis
ICHO	Iran's Cultural Heritage Organization
ICHHTO	Iranian Cultural Heritage, Handicraft & Tourism Organization
NIPA	Institute for Scientific Research and Planning on Monuments of Material Culture of Kazakhstan
UKM	Universiti of Kebangsaan Malaysia
UM	University of Malaya
UNESCO	United Nations Educational, Scientific, and Cultural Organization
SPACH	Society for the Preservation of Afghanistan's Cultural Heritage
TIKA	Turkish International Cooperation and Development Agency

GLOSSARY

Achaemenian	- Period in Persian architecture from the time of Cyrus the Great (d. 529 BC) until the death of Darius (330 BC).
Chahârtâq	- Four-arch
Chhatra	- the precious parasol umbrella and an auspicious symbol in Indian religions
Iwan	-Portico
Jamek	-Friday
Madrasa	-Religious School
Masjid	- Mosque
Mihrab	- is a niche in the wall of a mosque that indicates the *qibla*
Minbar	- Pulpit
Miraaj	- is the part of a journey that Muhammad took in one night, around the year 621
Muqarnas	- is a three-dimensional decoration of Islam architecture
Parthia	- is a region of North-Eastern Iran, best known for having been the political and cultural base of the Arsacid dynasty, after which the Arsacid Empire is then also known as the 'Parthian Empire'
Pishtaq	-Portal projecting
Qibla	- is an Arabic word for the direction that should be faced when a Muslim prays during Salah
Sassanian	- is the name of the last pre-Islamic Iranian empire
Squinch	- is a piece of construction used for filling in the upper angles of a square room so as to form a proper base to receive an octagonal or spherical dome
Takht-e-Jamshid	-Perspolis
Tropain	-Temple
Tromp-Patkana	-Persian name for a type of *squinch*

Chapter 1
Introduction

1.1 Domes

The dome is one of the most efficient shapes in the world such that it covers the maximum span with the minimum surface area for maintaining larger volumes with no interrupting column in the middle. Terminologically, it is defined according to the Oxford keys (1980, p. 12) "*as a round roof with a circular base*".

Architecturally, the dome generally is a vaulted roof having a circular, polygonal, or elliptical based and a common hemispherical or semi-spherical shape. From the structural point of view, it is a structural element of an architectural configuration that resembles the hollow upper half of a sphere. In fact, it can also be thought of as an arch which has been rotated around its vertical axis. Such domes can embrace the high level of structural resistance (Wikipedia, n. d.).

In Western architecture, Bowman (2003) elaborated that: "The domes are categorized according to their shapes of both the base and the section through the centre of the dome". Then he continued that: "*Their bases may have circular, square or polygonal (many-sided) features, depending on the plan of the drum (the walls on which the dome rests).*"

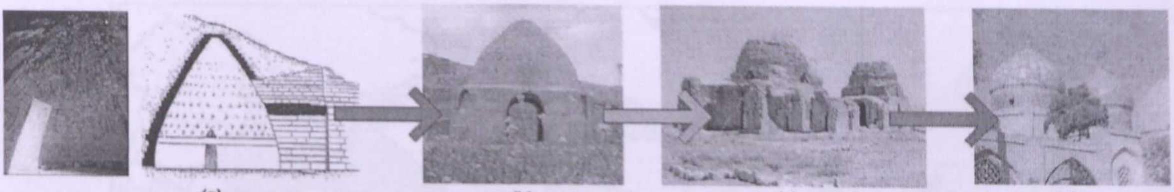
In the construction process, dome structures made of various local materials have a long architectural lineage extending into prehistory; they continued to be built of less flexible materials such as, stone, mud brick, and baked brick (Dome, 2007). The dome was employed as a roofing method where the absence of suitable timber material had made it impossible to construct a flat timber roof (Pirniya and Bozorgmehri, 1992).

Historically, there were various domical traditions in both the Western and the Eastern[1] architectures. B. B. Smith (1971) in his book titled '*The Dome: A study in the History of Ideas*' highlighted that the origins of the primary domes almost are uncertain: "These domical shapes, as an ancient and revered house form, were preserved in many cultures and gradually translated into more permanent materials as a family or royal tomb, a cult house and abode of the Great One, or as a utilitarian granary, sweat house and kiln."

Then again, Grabar (1963) restated, "there is no historical justification for the assumption that the domical vault was solely employed for the pure structural and environmental reasons in either brick or stone". Instead, all the evidence show that the early masonry vault forms including dome and tunnel vault were traditionally roof shapes were preceded for both logical and ideological reasons (Wanda, 2002). Smith (1971), however, differently concluded his ideas in transferring the domical ideas since their appearance as follows:

Hence, in tracing the evolution of the dome in any particular region, a particular distinction must be made between the cultural level, which the domical idea took shape and acquired symbolic values, and the historical period, which there was a social organization with the incentive, technical equipment, and craftsmen, firstly, to translate an ancestral dwelling into a tholos tomb (fig. 1. 1a), secondly, to turn a royal tent into a domical audience hall of brick, and finally to erect monumental hemispheres, or conoid domes, upon temples (fig. 1.1b), martyred, palaces (fig. 1. 1c), churches, baptisteries and mosques (fig. 1.1d).

[1] Refer to the sub-chapter 2.1.2, the difference between Eastern and Western domes for more discussion



(a) (b) (c) (d)

*Figure 1.1: Illustration on the Smith elaborations regarding dome evolutions since beginning over historic times: **a)** The corbel dome of the Treasury of Atreus, Mycenae (Wanda, 2002; Smith, 1971); **b)** Four-Taqi (four vaults) in Darehshar, Iran (photo by Maryam Ashkan, 2003); **c)** Domes of Sarvestan palace, Iran (photo: www.trekearth.com/gallery/Middle_East/Iran/East/Fars/Sarvestan/); **d)** Mausoleum of Moshtaq Ali shah, Iran (Photo by Maryam Ashkan, 2002).*

Historically, the earliest domes were found in the ancient Middle East[2], Central Asia[3] (fig. 1. 2, 3) and India in the modest buildings and tombs (Dome, 2007; Pope, 1965).

Figure 1.2: Map of Asia (Source: www.preventconflict.org/portal/nepal/nepal_maps_sasia.php)

[2] There are now seventeen countries within the Middle East region: Afghanistan, Armenia, Azerbaijan, Bahrain, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, United Arab Emirates, Turkey, and Yemen.

[3] Central Asia consists of the five former Soviet republics of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

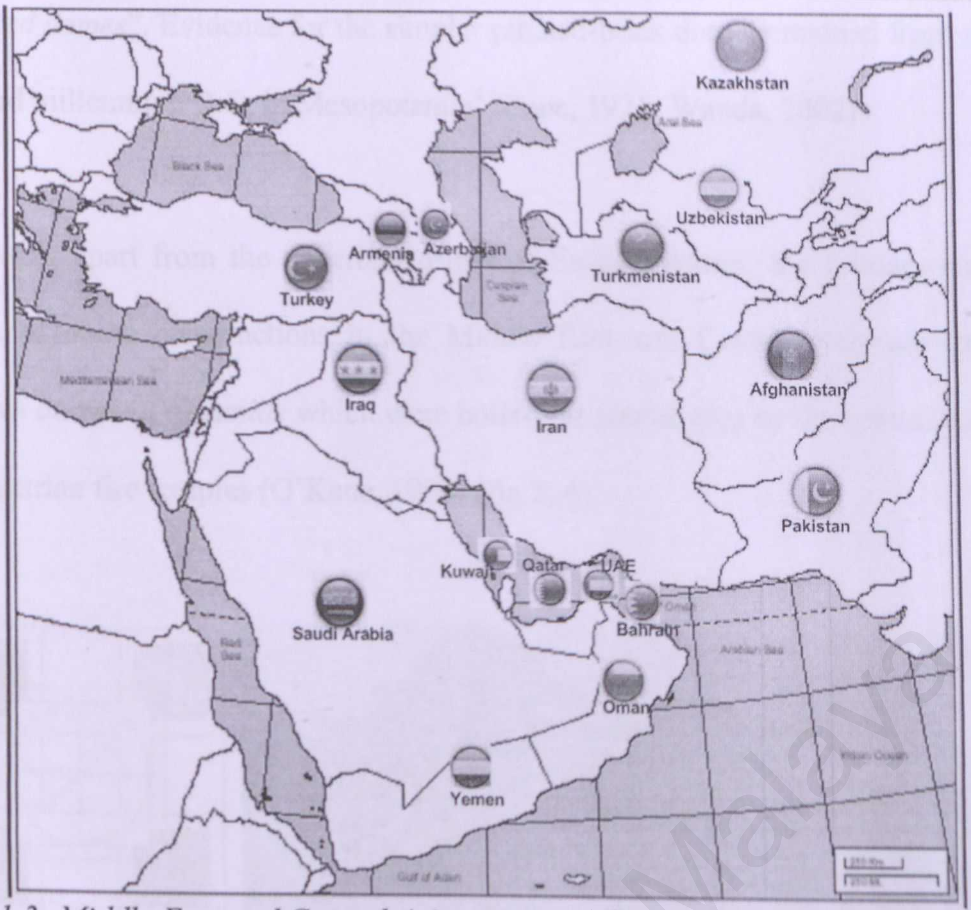


Figure 1.3: Middle East and Central Asia countries (Source: the Middle East Atlas online Resource)

Professor A. U. Pope (1971), who has done many investigations regarding Middle Eastern cultures, believed that essential causes of the continued development of domes in this region relied on their specific logical thoughts and symbolic meanings: "It was the mortuary, divine, royal and celestial meanings of these domical traditions with their symbolic ideologies which led to the popularity and monumental use of the domical shapes in India and the late Roman Empire, then in the Christian and Sassanian East, and later over Islamic periods."

1.2 Middle Eastern Domes Before the Coming of Islam

The earliest domes in the Middle East were associated with round buildings and were produced out of mud brick placed in layers which tilt slightly inwards, namely, "*corbelled domes*". Evidence for the simpler pitched-brick dome remained from as early as the 3rd millennium B.C. in Mesopotamia[4] (Pope, 1971; Wanda, 2002).

Historically, apart from the uncertain origin of Eastern domes, the primary surviving samples of dome constructions in the Middle East and Central Asia are the most enormous domes of *Sasanids* which were built over *chahârtâqs*[5]or the central chambers of Zoroastrian fire temples (O'Kane, 1998) (fig.1. 4).

Figure 1.4: Two examples of remains of Zoroastrian fire temples; ***a)*** *Niasar Zoroastrian temple in Kashan, Iran, (c. third A.D.);* ***b)*** *Four Taqi in Darehshahr, Ilam, Iran (uncertain date) (Plan: after Memarian, 1988 ;(Photos:* ***a)*** *Neda Qasemi, 2006;* ***b)*** *Maryam Ashkan, 2003).*

Soon after, Persian master builders had introduced an architectural innovation which had an imperishable effect on the dome architecture in the Middle East and Central Asia: "surmounting a dome on *squinches*" (Ashkan and Yahaya, 2009). In this regard, the primary well-known samples, which have often been presented in historic literature (Pope, 1976; Memarian, 1988; Pirniya and Bozorgmehri, 1990), are domes over the *Sarvestan* palace.

Bier (1986) believed that the domes of Sarvestan palace (also known as "The Temple of *Anahita*", about 350A.D.) are considered as the oldest brick domes in the world which topped the most splendid sacred monument constructed during this era. Its biggest

[4] Is the area of the Tigris-Euphrates river system, along the Tigris and Euphrates rivers, largely corresponding to the modern Iraq.
[5] Sacred buildings with four gates or doors that are scattered throughout Iran.

dome, with a semi-elliptical 12.80m span, and height of 20m, however, are not as enormous as the one surmounting the *Ardeshir* palace in *Firuzabad* (fig. 1.5).

Figure 1.5: Domes of Sarvistan palace with primary samples of squinches, Sassanid era. (Sources, photos: www.trekearth.com/gallery/Middle_East/Iran/East/Fars/Sarvestan/; after Pirniya and Bozorgmehri, 1992; Memarian, 1988).

In fact, decorative elements emphasizing the zone of transition at the palace of Sarvestân are carefully set off by dogtooth moldings above and below and lightened by four windows between the *squinches*[6] (O'Kane, 1998). Accordingly, with the Islamic conquest, several *Sassanid* sacred *chahar-taqis* (four vaults) were easily converted into the mosque main hall by inclusion of a *mihrab*.

Then regarding domes through Asia Minor, historically, Smith (1971) stated that: "The second method of dome construction appeared in the northern Syria and Harran in Turkey (fig. 1.6) known as the corbelled domes in which the mud bricks are placed horizontally in circular layers of diminishing circumference."

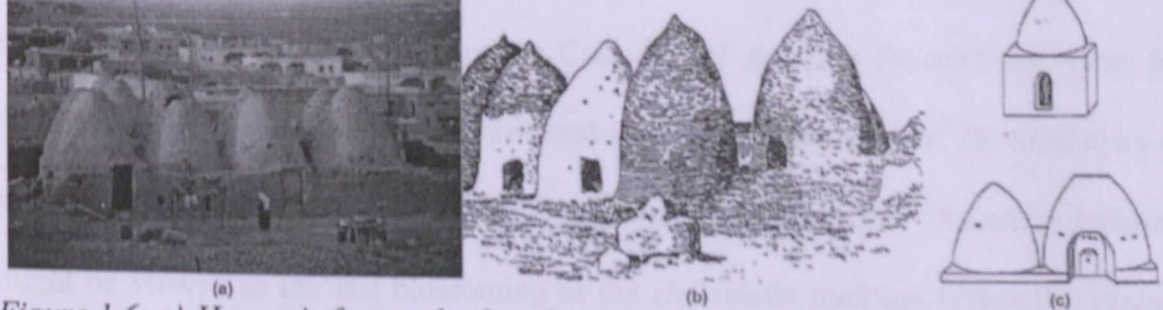


*Figure 1.6: **a)** Harran's famous beehive houses in Turkey; **b, c)** Syrian qubab village and its typical domes (Smith, 1971).*

[6] Refer to the sub-chapter 2-2, dome general definitions for more discussion.

Then after, the construction of wooden dome was widely increased through Asia Minor which combined the space of dome building with the flexibility and lightness of wood. On the other hand, wooden domes were usually covered with sheets of metals such as copper and lead, for protection against the weather. By the seventh century, wooden domes were normal methods of roofing churches, such as Sion church (456-460 A.D.) in Jerusalem in the Near East (Smith, 1971).

When the Arabs came to build the wooden Dome of the Rock, this method was thus the common appropriate approach for major religious buildings. The Dome of the Rock, which has likely been known as one of the world's architectural masterpiece in the early Islamic era, is an ample sample of transferring pre-Islamic cultures into the Islamic architectural style of domes.

The essences of non-Islamic influences on dome construction methods in the early Islamic architecture are boldly illustrated by Dogan Kuban (1974, p. 136) in his book titled: "*Muslim Religious Architecture*":

Art historians have kept up an unceasing flow of studies of the Dome of the Rock. In the context of Islamic architecture, it remains unique, but in that of Roman architecture its form is directly in line with the late tradition in Syria. All of its important features, from the interior double colonnades to the great wooden dome, have been shown to be faithful reproductions of features of the Cathedral of *Bosra* in the southern Syria. Its well-known mosaic decoration is considered as its only Islamic sense. Its vocabulary is syncretism and does not include representation of men or animals. The entire building might be viewed as the last blossoming of the Hellenistic tradition before the Islamic synthesis created its own formulas.

1.3 Middle Eastern Domes After the Coming of Islam

After the construction of the Dome of the Rock and introduction of using dome in Islamic architecture, thousands of masonry domes were built throughout the Eastern Islamic lands. Nevertheless, it has generally been recognized that domes (either as single domical buildings or in large complexes of building) have played a considerable part in Islamic architecture.

Grabar (1963) also strongly emphasized that: "Islamic domes vary considerably in size and in sumptuousness, but their number shows clearly the importance in the new Muslim culture of an architectural form."

But, the lack of adequate text indication or even of means to evaluate the existing evidence has constantly hampered the possibility of answering questions about the Eastern domes' styles and the architectural configurations, apart from their pre-Islamic origins.

A great deal is known about the construction and visual aspects of the Islamic domes in the Middle East and Central Asia. The works of M. Smith (1937) and Godard (1949) in Iran, of B. B. Smith (1971) in the near East, of A. Pope (1971) in Iran, and O. Grabar (1963, 2006) in the Middle East and Central Asia may be highlighted to illustrate the general features and historical considerations about developments of the Eastern domes and their meanings in Islamic architecture.

Nevertheless, much is still uncertain and vague, *especially with respect to the crucial problem of interplaying typologies with the exact geometry in the dome architectural compositions, the morphological aspects, common shape-patterns of architectural components of these Eastern domes since the early Islamic until the late Islamic epochs* which are the main concern of Part One of this Research.

In the Second Part, Research focused on the precise analysis of the pointed discontinuous double-shell domes as the greatest type of Islamic domes. Pointed domes, whether erected on single domical buildings or involved in huge complexes, are considered as significant and important items of Islamic architecture which were widely practiced for both architectural and symbolical purposes. This type of eastern dome includes the majority of monuments in Iran, Afghanistan, Kazakhstan, Turkmenistan, and Uzbekistan. They are well-known due to their graceful design, proportion of constitutions, various typologies, and specific configurations.

An Islamic or eastern double-shell dome is defined as the dome whose two shells have noticeable distances. Architecturally, they consist of three sub-types as follows: conical, bulbous, and pointed which is the matter of the second part of this Research. Such domes have played a significant role in the development of the Eastern domical architecture over Islamic eras.

Historically, pointed domes rapidly underwent continuous development since the tenth century when, despite initial Islamic hostility to construction of tomb structures, several dome funerary buildings had probably been built by the ʹAbbasid caliphs for themselves (Allen, 1983). Domed tombs had also been erected over the graves of many *Shiʹite* martyrs (Blair, 1983, pp. 83-84), and the respect paid to them by pilgrims may well have hastened the spread of the form.

Later on, in the *Ilkhanid* era, the primary idea of the discontinuous double-shell dome was introduced for resolving the conflict between the external appearance of the dome and the aesthetics of its interior chamber. The results were the appearance of imposing domes with shallower interior designs. Accordingly, such domes were widely developed into the variance types during the medieval Islamic era which have clearly reflected dynastic, religious and social distinctions as much as different construction techniques.

Eventually, more regular forms had extensively appeared after collaboration with the Islamic mathematicians who had introduced the use of certain proportions and geometric approaches in dome design. Because of this, more complex and regular shapes of the pointed domes were regularly constructed throughout the Middle East and Central Asia. It is interesting to highlight that the pointed typology of the discontinuous double-shell domes are the most synonymous form of domes in this territory.

Despite the existence of several historical considerations, the studies regarding their formal architectural language such as appropriate terminologies, morphological constitutions, typological organizations, and geometrical design are insufficient and the dispersed documents suffer from the lack of profound and principal analytical analysis. This Research, therefore, is aimed at filling the highlighted gaps into two provided parts by assessing the selected Eastern domes in the Middle East and Central Asia.

i. *Evolution of Islamic Domes over Historic Eras*

Domes were popular embellishments in the Mediterranean area for many centuries before the advent of Islam. Islam began as a religious movement in early 7th century Arabia and quickly spread throughout the Middle East (Smith, 1971). Before the next century Muslims had conquered and converted Byzantium and Persia, as well as parts of Asia, Africa and Europe. In fact, the technical and architectural developments of the domes in Islamic architecture embarked with the proceeding of Mediterranean and Middle Eastern architecture in the pre-Islamic era.

Then these meanings and architectural items were similarly translated in the newly encountered languages and grammars by those new Islamic civilizations (Smith, 1971). The domes are considerably varied in size and in sumptuousness, but their number shows clearly the importance in the new Muslim culture of an architectural form (Grabar, 1963).

Nevertheless, the dome in Islamic architecture is more than a history of developing form and style: it had resulted from combinations of cultural and environmental factors and also expression of the skills of traditional masters (Dome, 2008). For understanding the architecture of the Islamic domes in the Middle East and Central Asia, it is necessary to identify the architectural context of the Islamic dynasties who were ruling during various periods in this realm and their contributions to the dome developments.

Many dynasties [7]had appeared after the coming of Islam in 7th century Arabia in the Middle East and Central Asia. The most important ones, which directly helped in dome

[7] Refer to Chapter2 under sub-heading 2.2 the history of dome development in the Middle East and Central Asia, fig. 2.18 for more detailed discussion.

development, may be followed chronologically as follows: Samanids (819/1005 A.D.), Seljuks (1038/1194 A.D.), Ilkhanids (1256/1353 A.D.), Timurids (1371/1506 A.D.), Saffavids in Iran (1501/1732 A.D.), and Shaybanids in Central Asia (ca. 1506/ 1800 A.D.).

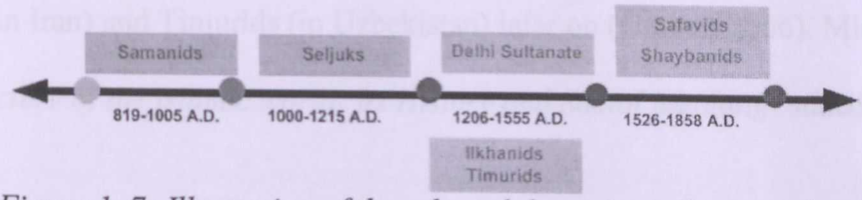


Figure 1. 7: Illustration of the selected dynasties to be considered.

The Samanid Empire was the first native dynasty to arise in Iran after the Muslim Arab conquest (and also after the Umayyads). It was renowned for the impulse that it gave to Iranian national sentiment and learning. According to Askarov (2007) the well-known process of Iranian renaissance began in Central Asia rather then in Iran in this period, and he saw the reasons for that in the difference of the social groups in these two parts of the Muslim world. The Samanid contribution to Islamic architecture indeed is very significant. Special attention was given to the formation and flowering of literature, sciences, and the arts. The primary signs of collaboration between mathematics and architecture brought to light in this dynasty are evidenced by the construction of the Ismail Samanid mausoleum in Bukhara as the early Islamic masterpiece (Pope, 1971).

The culminating expression of the Islamic dome renaissance in geometry and construction had begun in the second half of the ninth century by contributions of the Seljuk rulers (1000/1157 A.D.) culturally and traditionally. The mausoleum monumental buildings as "one of the world's greatest innovative architectural styles" was regularly constructed under their domain which later became a common practice in developing of the domical buildings. Such buildings topped with the various types of domes (Saud, 2003) such as conical and pointed. In addition to their constitutional designs, one shell and two shells domes had been built during this era.

After architecture had suffered severe degeneration caused by the Mongol invasions and their successor's Timur (producing a gap in the domical construction evolution), the material culture of the Middle East and Central Asia flourished again under the Ilkhanids (in Iran) and Timurids (in Uzbekistan) later on (Grabar, 2006). Michell (1978) in '*Architecture of the Islamic world: Its History and Social Meaning*' stated that:

> Architects and artists from all the lands, from Asia Minor, Azerbaijan, the Caucasus, India, Iran, and elsewhere were forced to contribute to the construction of often colossal state buildings of both a sacred and secular nature.

In this sense, enormous monuments topped with elegant discontinuous double-shell domes were extensively erected in the realm. Additionally, the pointed domes were placed over funerary buildings in the Ilkhanid epoch, in contrast to the Timurid domes which were built for the purpose of attaching to '*madrasa*' (religious school) and often in pairs (Hillenbrand, 1994).

The international characteristic style of the Timurid domes, which have been known for their high drums, imposing external features stabilized by projecting brick ribs, the use of meridians and wooden struts, was gradually faded and altered significantly upon the appearance of three specific local dynasties (Hillenbrand, 1999a): Saffavids in Iran (1501-1732 A.D.), Shaybanids in Central Asia (1600- ca. 1800 A.D.), and Mughals in India (1525-1858 A.D.; these types of domes are beyond the scope of this Research). As a rule of thumb, the dome architecture was quickly blended with local styles after the Timurids. In fact, it was dominated by a skilful use of a diversity of building materials cular architecture) and well-developed construction techniques existing in each (Stierlin, 2002).

vid architecture was actually the climax of skill and experience of Iranian ects where traditional forms were easily used in awesome scales. Emphasis on the ness of buildings, which had been started under Timurid rulers, continued by using arious types of the bulbous domes which effectively influenced Mughal dome tecture in India (Wilber, 1955). Bosworth (2002) in his book "*The New Islamic asties*" explained: "In the Shaybanids' style, the thin double-shelled dome forced by arches between the shell were continued to be built so that it can not be any particular developments after the Timurid samples."

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-Definition of Typology: It is stylistic organization of a domical edifice which basically deals with distinct arrangements of whether the whole components (vocabularies) as a system or constitution for creating diversities in a domical structure.

Morphologically, the construction of the Eastern domes, according to the numbers of shell(s) can be can be ranked as (fig 1.7): one shell (the earliest type of the Eastern domes: (OS-Type 1 and OS-Type 2), two shells and triple shells. Later may be called as an evolved form of the double-shell domes in such a way that a shell almost always plays whether a decorative role (Grangler, 2003) or considered structural component. The emergence of only a few examples of this kind of dome in comparison with the large numbers of the other sorts can also verify this statement.

Regarding the double-shell types, based on how these two shells are composed together, two subdivision groups had been defined (Ashkan and Yahaya, 2009; Hejazi, 1997): continuous and discontinuous, respectively. In continuous double-shell domes, sometimes, there exists no considerable distance between the shells (CD-Type 1), or they are connected by brick connectors (CD-Type 2), but very often the distance between shells is small (*see* fig 1.7; CD-Type 3).

It is necessary to say that the continuous two-shell domes can be called "an evolving stage" from the one shell domes to the two shells domes in the Islamic domical architecture development whilst the construction of the one shell domes had recurrently been continued up to the late Islamic era (Ashkan and Yahaya, 2009).

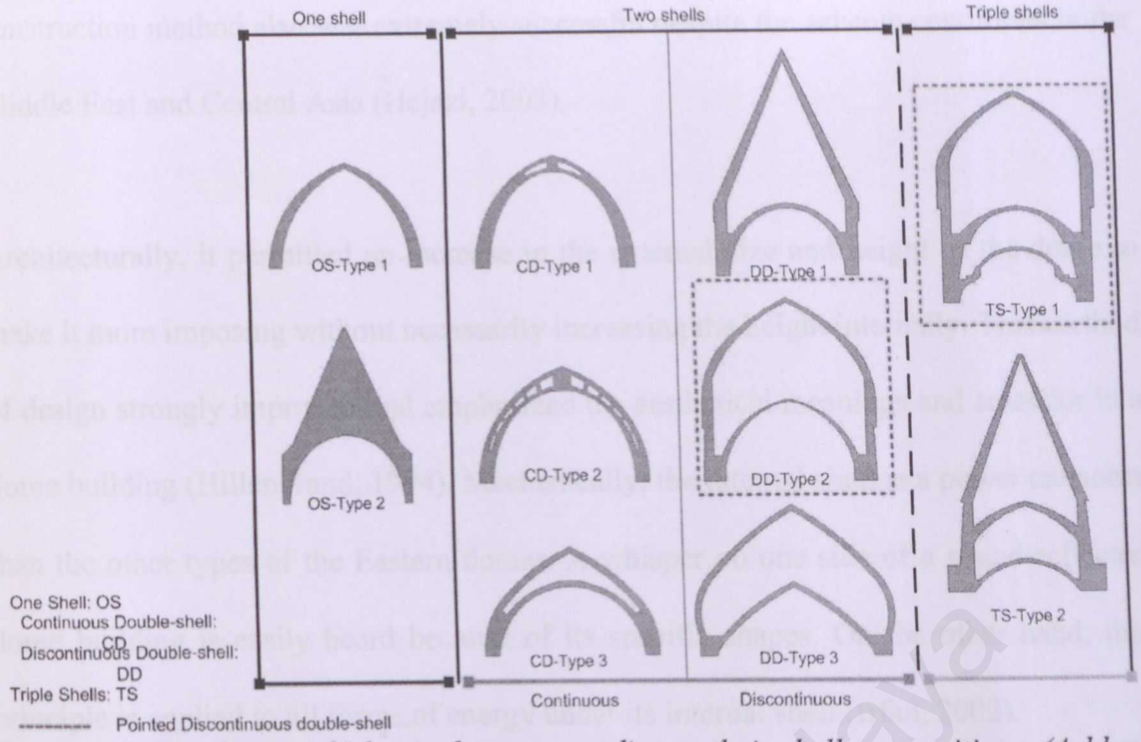


Figure 1.8: Typologies of Islamic domes according to their shell compositions. (Ashkan and Yahaya, 2009; Hejazi, 1997)

ii. *The Pointed Discontinuous Double Shell Domes*

In discontinuous double-shell domes, there is a considerable distance between their two shells. The discontinuity may start either from the base (*see* fig. 1.8; DD-Type 3) or from the top of the drum (DD-Type 1 and 2) which is considered higher than the other types of the Islamic domical typologies (DD-Type 2; TS-Type 1). According to the form of their external shell, there are three sub-types which are conical, pointed, and bulbous, accordingly[8].

Discontinuous double-shell domes offered several advantages. Firstly, the chief advantage was in divorcing the weathering surface from the inner shell and thereby substantially giving improved weather protection (Mainstone, 2001). Structurally, the weight for a given overall breadth of construction is reduced by using the light shells. Its

[8] Refer to Chapter 2, sub-heading 2.3.2, common typologies of the discontinuous double-shell domes for more discussion.

construction method also was extremely successful despite the seismic conditions in the Middle East and Central Asia (Hejazi, 2003).

Architecturally, it permitted an increase in the external size and height of the dome to make it more imposing without necessarily increasing the height internally. This method of design strongly improved and emphasized the aesthetical meanings and splendor in a dome building (Hillenbrand, 1994). Mechanically, the internal shell is a power enhancer than the other types of the Eastern domes. A whisper on one side of a sound-reflected dome building is easily heard because of its specific shapes. On the other hand, this principle is applied to all forms of energy under its internal shell (Irfan, 2002).

Historically, the discontinuous double-shell domes are, in retrospect, resulted in fairly continuous development of the practice of proportions in the dome edifice to reach the meaning of 'Centrality' in the Islamic architecture (Michell, 1978).

Primary existing samples of the pointed discontinuous two shells domes were discovered in the mausoleum buildings in the Seljuk epoch (Hillenbrand, 1996; Saud, 2003) without predetermined structural stability. In fact, their designs were an attempt at resolving a conflict between the external appearance of the dome and the aesthetic interior through the development of construction techniques. Eventually, more regular forms had extensively appeared following collaboration between the Islamic mathematicians who intervened to acquire the certain proportions and geometric approaches in the dome design (Ashkan and Yahaya, 2009).

As a result of geometrical knowledge developments, pointed domes eminently appeared within especial geometric contexts in the Ilkhanid and Timurid eras. In fact, the pointed typology of discontinuous double-shell domes includes the majority of the Islamic domes from the Seljuks until the Timurids eras when they reached to their high level of development. Despite the international and characteristics of the pointed domes, the conical and bulbous types have contained the regional styles inclusively which were developed based on vernacular architecture in certain territories such as Turkey (conical) and Iran (bulbous). The investigation of the pointed typology of discontinuous double-shell domes is the subject of the second part of this Research. In addition, the pointed double-shell domes may be regarded as the oldest and supreme shape of Eastern dome whereby the other styles (e.g., conical and bulbous) in fact, have relied on their architectural properties. Compositionally, they had appeared in advance of both elements and organizations.

1.4 Research Aims and Objectives

This Research was carried out with clear aims of assessing the formal architectural language of Eastern domes including their morphology, typologies, and their geometrical design in general point of view in the Middle East and Central Asia. Then, the second part of the Research assesses particularly the formal language of the pointed discontinuous double-shell domes which are their proper terminology, specific morphological features, typological re-definitions, brief structural properties, geometric design, and general construction techniques.

In this regard, the Research, therefore, firstly reviews the historical background of the Eastern domes for the purpose of understanding general aspects of Eastern domes, their symbolic meanings, historical dynasties achievements over historic time since pre-Islamic until the late Islamic eras Eastern architecture. In addition to those objectives, firstly, fifty three samples were selected from eight Middle Eastern countries and were deeply examined based on the proposed approaches (Chapter Three). In this part of Research, those samples have been chosen whether their textual documents were available to consider the specific features of dome style in those eight studied realms.

Secondly, following the study of literature and samples in the part one of Research, it was demonstrated that the pointed discontinuous double-shell domes were recognized as the most dominant and international features of the Islamic domes since the medieval Islamic era in the Middle East and Central Asia. Other sorts of discontinuous double-shell domes, namely, conical and bulbous, however, were built regionally based on the vernacular architectural properties and do not reflect the whole characteristic of Islamic domes. Because of this, the Research studies in greater detail their origin, developments, geometric significances, and common architectonic characteristic structures, and their typological features (Chapter Two).

Regarding the second part of this Research, common geometrical approaches, especially *al-Kashi* were surveyed for developing a unique systematic geometrical approach for the analysis of twelve case studies.

By using geometrical essences of the *al-Kashi* approaches, the developed four-centered profile based on new geometrical parameters has been presented according to a specific parametric system. In this regard, their geometrical indicators have been formulated according to the new proposed parametric system (Chapter Three). In terms of estimating the structural stability of such domes, four popular samples of the pointed discontinuous double-shell domes have been modeled by using the ABAQUS structural soft ware (Chapter Three).

To sum up, the Research concluded with the derivation of commonalities of vocabularies[9] of the fifty three samples, presented as shape-patterns and their distributions in those studied zones in Chapter Five. The overall typological considerations have also been carried out to identify their grammar[10] characteristics as well as their diffuseness throughout those selected countries. Both of these qualitative examinations, however, have been accomplished by using a qualitative proposed table. In addition, a graphical map is set up to show regionally the common shapes of domes in the Middle East and Central Asia.

Owing to the second part of Research and analysis of those twelve case studies, the formal architectural language of the pointed discontinuous double-shell domes have been deduced which embrace their morphological aspects, compositional characteristics, and finally structural traits. In this sense, the cross-sections of domes, which were collected from secondary documents, were re-drawn and their drawing mistakes thoroughly were revised (Chapter Five).

The developed four-centered general profile is geometrically utilized based on new geometrical indications for analyzing the geometrical design of such domes. Then, by using this method, the common geometrical prototype, which is generally shared by those studied cases, are generated and formulated according to the proposed parametric system (Chapter Five). In summary, this Research was carried out based on the following objectives:

I. To exploit general understanding of historical origins of Eastern domes, their developments process, evolutions, meanings, proper terminologies,

[9] Refer to page 24 for the extensive elaboration of vocabularies.
[10] Refer to page 24 for the extensive elaboration of grammars.

their architectural vocabularies, and compositional grammars (achieved in Chapters Two and Five);

II. To understand formal language of Eastern domes, architecturally including their morphology and various typologies of Eastern domes in the Middle East and Central Asia (achieved in Chapters Two and Five);

III. To identify distributions of different shapes of Eastern domes in the Middle East and Central Asia (achieved in Chapters Three and Five)

IV. To understand formal architectural language of the pointed discontinuous double-shell domes including their origin, development process, proper terminologies, distinct typologies, morphological aspects (achieved in Chapters Two and Five) ;

V. To understand the relation between the geometrical design and dome over Islamic eras in order to generate a specific geometrical approach for analyzing the majority of domes. Such a method can be employed, not only to estimate other sorts of Islamic domes, but it may also establish roles for estimation of any Eastern temporary domes (achieved in Chapter Three and Five);

VI. To derive common geometrical prototype of the pointed discontinuous double-shell domes according to the proposed approach (achieved in Chapter Five); and finally

VII. To understand structural characteristics and general construction method of the pointed discontinuous double-shell domes (achieved in Chapter Five).

1.5 Research Methods

In order to achieve those objectives, two steps of this Research are organized as follows:

Part I: Review of Primary and Secondary Sources

To establish main Research gaps, aims and objectives, a general literature study was comprehensively conduced through the following contents: both primary and secondary sources related to the Islamic architecture contexts and their historical developments, the particular architectural characteristics of both pre-Islamic and Islamic dynasties throughout the Middle East and Central Asia, the dome characteristics, related meanings in different religions, main differences between the Eastern and Western domes, as well as the vernacular properties of domes in each region of the Middle East and Central Asian countries.

In this regard, special attention was given to recognizing the conservation projects of domical heritage buildings and those problems faced since 2001 in Iran, Afghanistan, Kazakhstan, and Turkmenistan. It is necessary to highlight that such information is scarce and scattered data suffers from lack of intense comparative analysis of their architectonic conceptualism in every region of the Middle East and Central Asia archives in comparison to the number of historic domes as majority of projects have extensively been carried out with the long duration (more than five years). Related delays are results of structural properties of the domes, collaborations of international experts and organizations, and financial problems.

Nevertheless, two PhD theses from the Michigan State University (2002), and the Shahid Beheshti University (National University of Iran, 2007); two Master theses from the University of York (2005) and University of Carleton (Ontario, 2000) were entirely reviewed.

In order to get secondary information of case studies, photos, partial restorations, thirteen national and international projects (whether completed or on-going) in the four countries of Iran, Afghanistan, Kazakhstan, and Uzbekistan were completely considered. In addition, materials on the projects were mainly collected (for both Parts of Research) from the Ministry of Culture & Youth Affairs in Afghanistan, the Iranian Cultural Heritage Organization documentation centre (ICHO), the Iranian Ministry of Cultural Heritage, the Iranian Cultural Heritage, Handicraft & Tourism Organization (ICHHTO), the Institute for Scientific Research and Planning on Monuments of Material Culture of Kazakhstan, and the National Department for the Protection of Turkmenistan Historical and Cultural Monuments.

Three most important projects, which were recently carried out, can be numbered as follows:

1. Nomination and inscription of the mausoleum of the Khaja Ahmed Yasawi (Timurids, 1389/1405 A.D., Kazakhstan) in the UNESCO world heritage sites' list, inscribed 2002, Republic of Kazakhstan: architect, Nurgaly Kimazhanov, the project manager at the site for nine years, Hakki Egemen;
2. Conservation of the Timur Shah Tomb (Abdali, 1793 A.D., Afghanistan), project duration: 2003-2005, architect, Dr. Urs Mueller, deputy minister of culture: Ghulam Rasoul Yosoufzai, director of restoration and preservation of historic monuments: engineer Abdul Ahad Abassy;

3. Conservation of the Uljatu mausoleum (Ilkhanids, 1307/1313 A.D., Zanjan,Iran; UNESCO cultural heritage site), project duration: 1990-2007, architect and project manager: Professor Hadi Nadimi.

In 2005 and 2006, during my transfer from Universiti Kebangsaan Malaysia to the Universiti Malaya (UM), two trips to Iran were also made with the objectives of acquiring second hand information on the current states of related dome architecture and conservations by meeting and consulting with the senior officers in the Iranian Cultural Heritage Ministry, who were involved in so many national and international conservation projects for the two purposes;

-Firstly, to understand the issues surrounding the domocal buildings, information documents drawings, photo albums, and methods;

-Secondly, to get contact persons and be introduced to architects, site directors and engineers in Kazakhstan, Afghanistan, and Uzbekistan for obtaining information about all recent projects of their countries' domical buildings.

In order to get copies of all the latest domical information, drawings, photos, research and conservation projects, the archives of the following universities had been considered completely: University of Tehran, Tehran (oldest University in Iran: Department of Architecture, Faculty of Architecture and Urban Planning), University of Shahid Beheshti, Tehran (National University of Iran, Faculty of Architecture and Urban Planning), International University of Imam Khomeini, Qazvin, (Department of Architecture, Faculty of Architecture, Conservation and Urban Development).

Several contacts were made with site directors, architects, engineers, ministers of cultural heritage, organizations, collaboration officers and whoever had been involved in any projects on domical buildings in Iran, Afghanistan, Kazakhstan, and Uzbekistan in order to get their latest formal drawings, background information, photos and formal documents.

PART II: Samples and Case studies

The Research adopts a qualitative method as the main strategy for secondary data collection as the main source. The Research was basically divided into the two different parts: firstly, general aspects of the Eastern dome were studied through the selection of fifty three samples of domes since the early Islamic era until the late Islamic in Iran (11 samples), Iraq (5 samples), Afghanistan (6 samples), Pakistan (7 samples), Uzbekistan (7 samples), Turkmenistan (5 samples), Kazakhstan (one sample), and Turkey (11 samples).

The famous and dominant examples, which have exposed the specific dome styles, were especially selected. In meanwhile, issues regarding to buildings located in Turkey, Pakistan, Turkmenistan, and Iraq have deduced from several studied books, international museum WebPages, tourism catalogues, Iranian local libraries, the archives of Iranian universities, and several WebPages of Islamic architecture.

In the part one of Research, the aforementioned countries were categorized into four specific zones (Iran & Iraq, Afghanistan & Pakistan, Turkey, Uzbekistan & Turkmenistan & Kazakhstan) according to their geographical similarities and dome characteristics. The four provided tables were set up to evaluate six defined characteristics of domes. In fact, those tables were utterly constructed based on the derived common architectural characteristics of domes which are vocabularies and grammar:

I. ***Definition of Vocabularies of dome*:** One of the tenets of morphological survey is essentially to find out the programmatic approach for clarifying typological commonality of Eastern domes. Considering again at the configuration of traditional Eastern dome as a sentence clearly indicate its identical elements as vocabularies. Because of structural requirements, though, the sequence of the identical elements of an Eastern dome is constant as follows: ***load bearing system, transition tier, drum*** and finally ***shell(s)***;

II. ***Definition of Grammar of dome composition***: Considering again at the configuration of traditional Eastern dome as a sentence clearly indicate that its grammar for setting words, vocabularies of a dome herein, into a sentence may call as its grammar which are: ***simple*** or ***compound***.

Secondly, results from the part one of Research demonstrated that the pointed discontinuous double shell domes are the most important feature of Islamic domes. They also involved the majority of the Eastern Islamic domes in comparison with the other typologies of the discontinuous double shell-domes such as: conical and bulbous.

In this regard, twelve case studies of the pointed discontinuous double-shell domes, which were built during the Ilkhanid (1200-1370 A.D.), Timurid (1370-1507 A.D.), and Shaybanid (1600ca. 1800 A.D.) dynasties since the medieval Islamic era until the early late Islamic era, were selected from the fifty three samples for the next stage of this Research. Geographically, these domes are located in Iran, Afghanistan, Kazakhstan, and Uzbekistan. The required information in this part of Research collected from secondary data and documents.

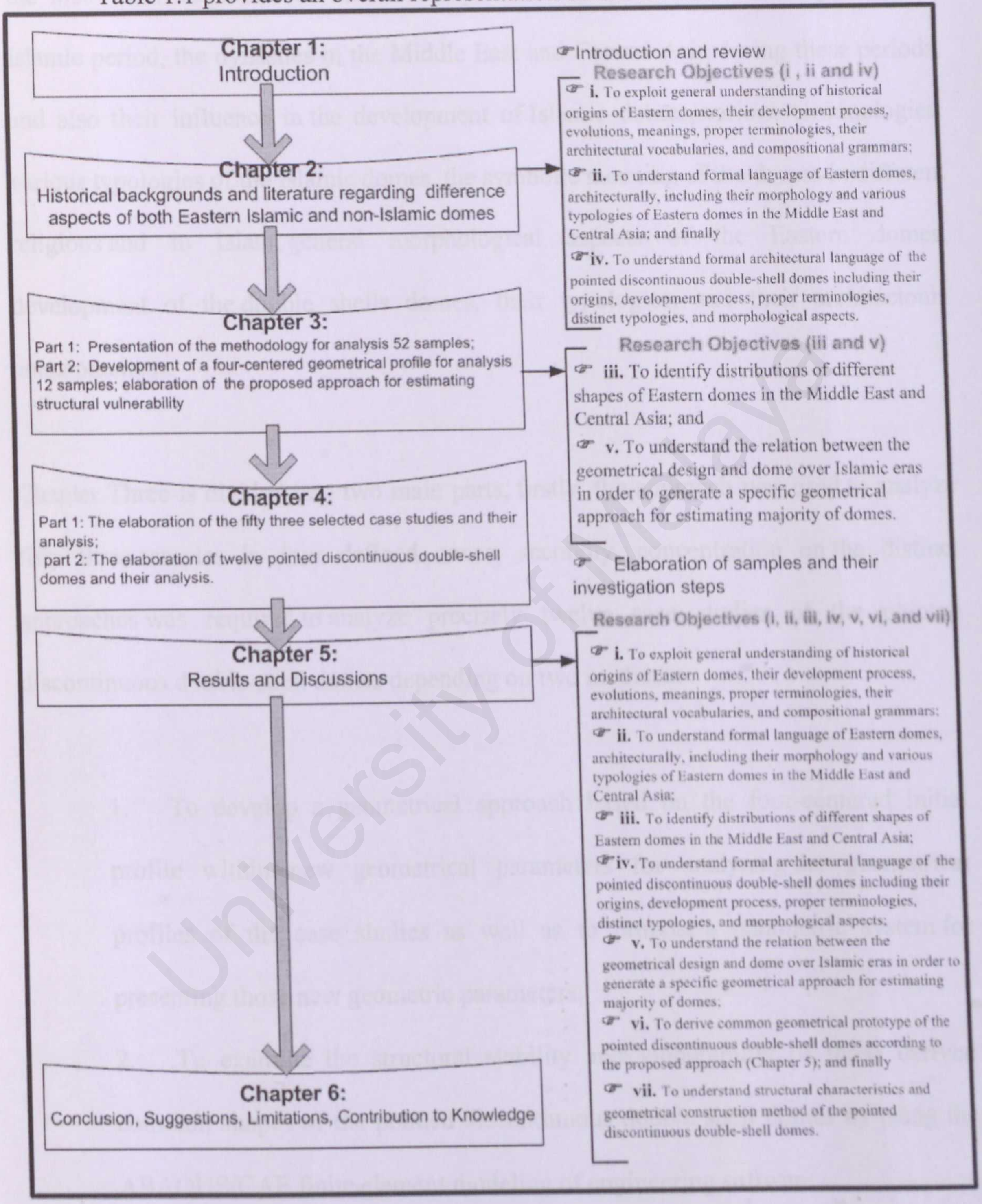
The studied periods and selected dynasties are particular causes for developing the pointed discontinuous double-shell configurations and their designs throughout the Middle East and Central Asia that were never surpassed in other periods. Thus, the morphological features, typological stylistics, geometric design, structural vulnerability and associated construction techniques of those twelve case studies are precisely considered and addressed.

By using the *al-Kashi* geometric essences, the developed geometrical approach had been generated and formulated based on the new developed geometrical parameters, for the purposes of analyzing the geometric design of those selected samples; but it also has potential to deduce the common profile prototype of the bulbous type of Islamic domes in the Middle East and Central Asia.

Total information regarding those six case studies (mosques) located in Iran were gathered during my trip in 2006. The data of those three samples of shrines and mausoleums are deduced from their restoration documents and studying researches which have been available in the Iranian Cultural Heritage Organization documentation centre.

1.6 Structure of Research

Table 1.1 provides an overall representation of this Research structure.



Chapter one introduces the bases of Research structure, aims and objectives, Research steps, methods, and finally the ways of data gathering.

Chapter Two includes Research backgrounds and historical literature such as main definition of Eastern domes, the main differences between Eastern and Western domes, the historical background of their developments since ancient times through the late Islamic period, the dynasties in the Middle East and Central Asia during these periods, and also their influence in the development of Islamic domes, various terminologies, various typologies of the Islamic domes, the symbolic meaning of the domes in different religions and in Islam, general morphological aspects of the Eastern domes, development of the double shells domes, their typologies, and their architectonic conceptualism.

Chapter Three is divided into two main parts, firstly, the approach was used to analyze fifty three samples in four defined zones; secondly, concentration on the distinct approaches was required to analyze precisely twelve case studies of the pointed discontinuous double-shell domes depending on two methods:

1. To develop a geometrical approach based on the four-centered initial profile within new geometrical parameters for analyzing the geometrical profiles of the case studies as well as to propose a parametric system for presenting those new geometric parameters;
2. To examine the structural stability and vulnerability of those derived common shapes of the pointed discontinuous double shell domes by using the ABAQUS/CAE finite element modeling of engineering software.

Chapter Four concentrates on the brief explanations of fifty three samples by using the provided tables. The detailed illustrations of selected twelve case studies of the pointed discontinuous double-shell domes included their historical background, date of building, building usages, building types, location, client (if available), and so on.

Chapter Five provides the whole results obtained from analysis of data into two parts. Part One includes the derived results from the analysis of fifty three samples of the Islamic domes, their general architectonic aspects, components, geometry, their frequency in the Middle East and Central Asia, and also their derived analogical patterns.

Part Two contains the derived results from the analysis of twelve case studies of the pointed discontinuous double-shell domes; these are their architectonic components, general features, geometry, typologies, construction techniques, structural vulnerability, and common profile prototype of such domes.

Chapter Six provides a summary of contributions to knowledge, conclusion, limitations, and suggestions for future work. To sum up, the Research presents primarily the general and comprehensive overviews of developments of the non-Islamic and Islamic Eastern domes, their origins, typologies, morphological and architectural patterns from the ancient era through the late Islamic era in the Middle East and Central Asia. In this regard, the specific qualitative multi-fold method for considering fifty three samples was developed for the purposes of understanding the Eastern domical general configurations, architectural vocabularies, and conceptualisms.

Then, apart from the varieties of the existed typologies of the Islamic domes, the pointed discontinuous double-shell domes, as the most dominant feature of Islamic domes, were examined comprehensively, such as, their origins, historical background, morphological aspects, sub-typologies, construction techniques and structural vulnerability. By using the essences of *al-Kashi* geometric approaches, the four-centered initial profile was developed based on the new geometrical parameters to estimate the geometrical design of twelve cases studies. The specific parametric system was proposed for presenting geometrical indications of this generated initial profile. The developed geometrical method has the potential for use as the basic approach for considering other sorts of the Eastern domes whether historic or modern styles.

This work fills a gap in the existing literature on Islamic domes. The results of this study are also expected to contribute in conservation and restoration of domical structures especially in Central Asia and the studied regions.

Chapter 2
Historical Outline of Origin and Developments of the Eastern Domes

2.1 Introduction

Domes have been called “the kings of all roofs”, and they cover some of the most important buildings existing in every religion in the world. Domes are curved structures (they have no angles and no corners) and they enclose an enormous amount of space without the help of a single column. Despite their thinness, domes are some of the strongest and stiffest structures in existence today.

Two distinct trends of dome developments exist in both the Western and Eastern architectures, before and after the appearance of Islam. In fact, the influence of Islamic domes in Western architecture cannot be disregarded. The Eastern domes had had the long and still uncertain pre-Islamic origins that basically proceeded into the early Islamic architecture as a major aesthetic theme of their architectonic conceptualism. Then, they appeared and developed rapidly in variety of shapes and sizes as the fundamental part of the religious building. Nevertheless, there seems to be regional districts and characteristics for their morphological aspects and geometrical parameters which may uniquely call as their visual vernacular language of Islamic architecture.

Thus, through a systematic review of these historical upheavals since the pre-Islamic until the late Islamic era, knowledge of their constitution evolution, especially in Islamic contexts and morphological concepts, can generally be gained. Also, by comparing dome developments in both Eastern and Western traditions, distinct features of their architectural components can be clarified.

What can be learned from these overall historic literatures are a projection of useful “road map” to the more relevant overviews of the aspects and characteristics of the

Eastern domes. This chapter establishes firstly the proper dome terminologies, symbolism meanings, their general concerns, and finally establishment of main differences between the Eastern and Western domes. The development of Western domes is also briefly elaborated. Then, the chapter focuses specially on the origin and evolution process of both Islamic domes and pointed discontinuous double-shell domes.

Consequently, this chapter provides overview on the general morphological aspects and typologies of domes, their adopted features from the non-Islamic architecture to the early Islamic architecture, and also related grammars. In this sense, the generic components and/or general vocabularies of both Eastern domes and the pointed discontinuous double-shell domes have additionally presented. These results were used as tools to find multi-fold analytical method to analyze such domes and their associated architectural concepts.

2. 2 Dome General Definitions

There were substantially two construction techniques for covering a building in the historic era (Pirniya and Bozorgmehri, 1990):

- Flat roof with use of the wooden beam and pole system in the early ancient time; and
- Different kinds of the curved roofs such as arches, vaults, and domes.

Nevertheless, the masonry corbelled arch is one of the oldest types used in construction of bridges. The first known ones were probably built in the Middle East around 5500 years ago. There is no doubt that the domes are the developed shape of the arches later on through developing construction techniques and structural knowledge. It seems likely that the dome originated as a roofing method where it was impossible to make a flat timber roof in the absence of suitable timber (Pirniya and Bozorgmehri, 1992). Historically, the dome is one of the earliest types of buildings which was built on circular bases and is one of the few structural forms which have had a continuous history and evolution extending to the present time.

Poole and Giambo (2007) provided a detail elaboration of the basic definition of term of dome: ***"The Term Dome*** (Latin *domus* meaning a house) is generally an architectural term often used synonymously with cupola. It is one of the multi-conceptual form with its great quality in harmony which were exceedingly used for symbolism (formalist aspect), purposed as curve roofing (structural aspect), and finally providing a contrast of special space-design for the architectural purpose. It is interesting to highlight that majority of primary domes had been erected either for presetting symbolism meanings (e.g. Sanchi Stupa) or for covering as roofs (e.g. corbel vaults). As results of development construction knowledge, theses goals, later on, were combined together. The dome's form can probably be gained by rotating a cross-section of arch around its vertical axis (fig. 2.1)."

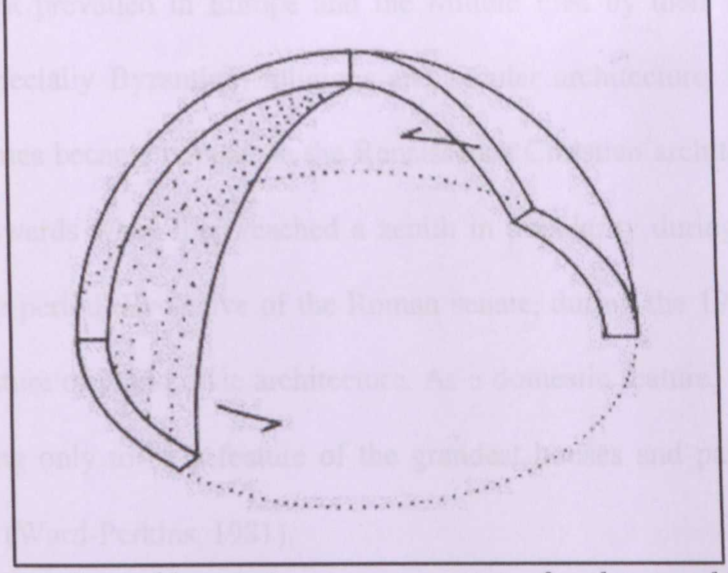


Figure 2.1: Dome is formed by rotating a cross-section of arch around its vertical axis (Altin, 2001).

Strictly speaking, it signifies the external part of a spherical or polygonal covering of a building, named, "the cupola" which is the inner structure, but by usage dome generally means the entire covering. Terminologically, it is also loosely used, as in the German *Dom* and the Italian *Duomo*, to designate a cathedral, or at times, to signify some other building of importance. A dome was constructed of any material such as wood, stone, mud brick, and baked brick (Poole and Giambo, 2007).

On the other hand, the dome is a roof; its base can be a circle, an ellipse, or a polygon, and its vertical section a curved line, concave towards the interior. Hence domes can be called circular, elliptical or polygonal, according to the shape of their base. The most common form is the spherical, in which case its plan is whether as a circle or a segment of a circle. The cross-sections or external shapes of domes, particularly the Eastern ones, are, sometimes, semi-elliptical, pointed, and bulbous and so on; whereas, the Western domes often appeared in whether curves of contrary flexure or bell-shaped (Poole and Giambo, 2007).

Domes were first prevailed in Europe and the Middle East by their frequent use in Roman (and especially Byzantine) religious and secular architecture. In the Western architecture, domes became popular in the Renaissance Christian architecture since the 15th century onwards when they reached a zenith in popularity during the early 18th century Baroque period. Evocative of the Roman senate, during the 19th century, they became as a feature of grand civic architecture. As a domestic feature, the dome is less common, tending only to be a feature of the grandest houses and palaces during the Baroque period (Ward-Perkins, 1981).

Today, domes are seen as a common feature in ecclesiastical architecture of many varying creeds. On the other hand, the dome symbolic meanings are as a fundamental cause for rapid development of their architectonic items through both the Eastern and Western architecture (Smith, 1971).

2.2.1 Dome Symbolism

Human beings' ability to manipulate symbols allows them to explore the relationships between ideas, things, concepts, and qualities (Kentish, 1997). Sometimes, the symbolic aims may be met by the structural abilities. The dome had had distinct meanings before and after the appearance of religions between various ancient countries. Generally speaking, one can associate distinct aspects in the development of domes. The symbolic idea derives from its shape rather than being the solution to roofing of large space without inner support (Vafai and Farshad, 1976).

One of the oldest specific symbols of the dome is the vault of heaven; that is why domes in ancient Persia were always painted blue or black. The dome generally is a symbolic form of standing heaven in architectonic language. Long before masonry domes could be built, the hemisphere was associated with the heavens as a "cosmic canopy," and throughout history domes have been decorated with stars (Homan, 2006).

Domes imply the meanings of the circle and more, since a dome is a covering. In this connection, it is important to note that, in the geometrical symbolism of the cosmos, all circular forms related to the sky or heaven (fig. 2.2a). Logically, every external image is complemented by an inner reality that is its hidden internal essence. The dome's outward form underlines the quantitative or physical aspect that is obvious, and easily and readily intelligible. It is represented in the shape of a building with dome, the shell of a vessel, the body of man, or the outward form of religious rites. Meanwhile, the essential qualitative aspect is the hidden (i.e., presented in all beings and things) (Kentish, 1997).

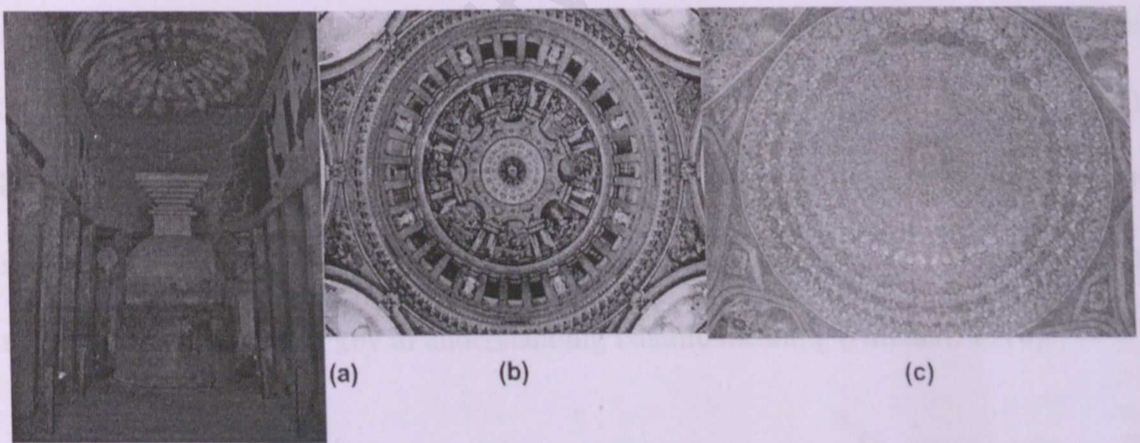

(a) (b) (c)

*Figure 2.2: Emphasis on the centrality and unity in distinct thoughts; **a)** Ellora & Ajanta caves, India (Kentish, 1997); **b)** St. Paul's Cathedral, London (Source: www.explore-stpauls.net/oct03/textMM/DomeConstructionN.htm); **c)** Tilla Kari mosque, Uzbekistan (Source: www.panoramio.com/photo/11533138; by Prof. Richard T.Mor)*

After the appearance of religions, the meaning of the dome was essentially associated with God. The dome thus becomes a symbol of the cosmic house of God which in turn has a dual meaning in some religions, as the House that God inhabits (Heaven, and the house that encompasses Man) The Universe. The dome acts therefore as a transition between the infinite unity of its central point, through the duality of its symbolism into the concretization of the four-sided chamber, which supports it, and which symbolizes the fourfold nature of mankind: fire, water, earth, and wind.

The sanctuary or chamber is the place where God and Mankind meet and can converse. The natural symbol for this is the Universe which expresses the infinite creativity of God while enclosing mankind in a protective space. Because of this, domes also play a very important part in the religion architecture where they almost always represent and symbolize different aspects of every religious building such as church (fig. 2.2b). The dome's purpose is to remind people that to gain God's blessing, it is necessary to accept salvation through Christ. In an orthodox church the domes have pictures of Jesus whereas in Islam figures are forbidden during worship (Kentish, 1997).

Domes can also be found in Islamic places of worship, called 'mosques'. They are associated with three of the principles of reversibility recurring throughout religious thought, in particular Islam, namely 'paradise', 'earth' and 'cosmos' (Irfan, 2007). Logically, dome architecture in Islam represents also the spiritual and physical aspects in the lives of Muslims and revolves around the Concept of Unity *(tawhid)*. The idea of a center or axis is a main key in understanding Islamic meaning (Michell, 1978).

On the other hand, Islamic architecture originates essentially from the Qur'anic message, whose values are aimed at translating those meanings into the plain special shape physically. The centralization of God in the Universe and the spiritual world is echoed in the central focus of the Ka'ba on earth (set with corners to cardinal directions), and on the dome of the mosque in the Islamic city (Kacar and Durukal, 2006).

The dome of a mosque is circular and its center point is where in fact, all Islamic patterns begin. It is an apt symbol of a religion that emphasizes one God, symbolizing also the role of Mecca, the center of Islam, toward which all Muslims face in prayer. The circle has always been regarded as a symbol of eternity, without beginning and without end, and is not only the perfect expression of justice (equality in all directions in a finite domain) but also the most beautiful parent of all polygons, both containing and underlying them.

Although, the symbolic meanings are somehow used synonymously between Christianity and Islam, but there exists one main difference in the architectural conceptualism of both Eastern and Western domes.

2.2.2 The Different Characteristics between Eastern and Western Domes

Primary domes, firstly, appeared on the smallest buildings such as, round huts, tombs in the ancient Middle East, India, and the Mediterranean in solid forms. The Romans introduced the large-scale masonry hemisphere. In this regard, a dome exerts thrust all around its perimeter, and those earliest monumental examples required heavy supporting walls. Byzantine architects invented a technique for raising domes on piers, making the transition from a cubic base to the hemisphere by erecting four *pendentives*; On the other hand, *squinches* were widely used for the same purpose in Islamic domical architecture (Dome, 2007).

Architecturally, One of the main problems of dome construction was the transition from a square space or area into a circular domed base. Usually there was an intermediary octagonal area from which facilitated converting to this circular disc; although there was still the problem of converting from square to octagon (Dome, 2007). Two main methods were adopted; these were the *squinch* and the *pendentive*. These approaches, in fact, may reflect the essential difference between the Eastern and Western domes. The *squinch* is a mini-arch which is used to bridge a diagonal corner area whilst a *pendentive* is an inverted cone with its point set low down into the corner and its base at the top providing a platform for the dome. *Squinches* are the main method of transition in pre-Ottoman architecture; whereas, *pendentives* appeared rather after the sixteenth century in Western architecture (Dome, 2007).

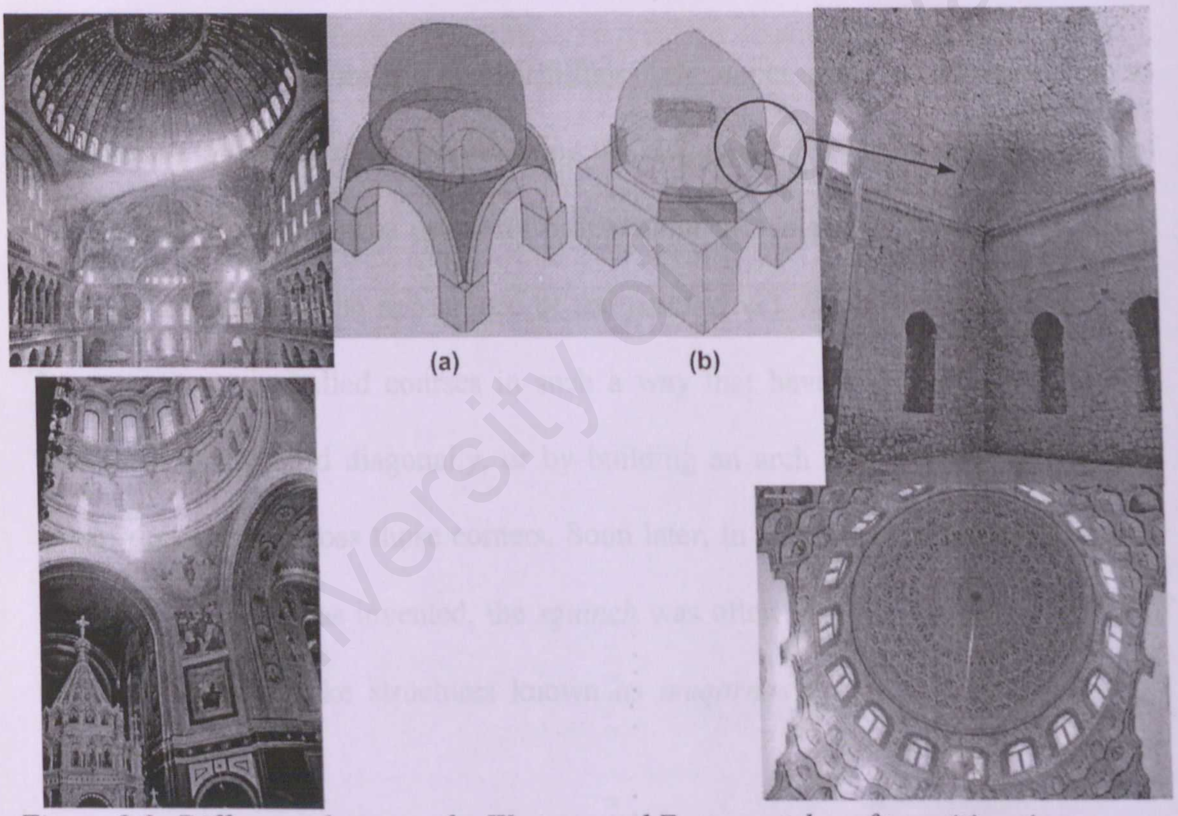


*Figure 2.3: Difference between the Western and Eastern styles of transition tiers (Compiled by Maryam Ashkan); **a)** Pendentives, primary sample: Hagia Sophia church, Turkey; **b)** Squinches, primary sample: Ardeshir palace, Iran.*

- ***Pendentive***: is a constructive device permitting the placing of a circular dome over a square room or an elliptical dome over a rectangular room. The *pendentives*, which are triangular segments of a sphere, taper to points at the bottom and spread at the top to establish the continuous circular or elliptical base needed for the dome. In masonry the *pendentives* thus receive the weight of the dome, concentrating it at the four corners where it can be received by the piers beneath (*see* fig. 2. 3).

Primary attempts for construction of *pendentives* were made by the Romans and full achievement of this form was reached in Hagia Sophia at Constantinople (6th cent.) by the Eastern Roman Byzantine Empire. *Pendentives* were commonly used in Renaissance and baroque churches, with a drum often inserted between the dome and *pendentives*. In addition, the *pendentive* is comprised of the geometric shape of a triangle; this further makes a strong base to withstand the dome.

- ***Squinch*** is architecturally a pier for filling in the upper angles of a square room so as to form a proper base for transforming the octagonal area to the spherical base of dome. Such a solution was primarily proposed in the palace of Ardeshir, at Firouz Abad in Iran (before the appearance of the *pendentive*). *Squinches* were formed by four prominent corbelled courses in such a way that have filled four corners with whether a vise placed diagonally, or by building an arch or a number of corbelled arches diagonally across those corners. Soon later, in Islamic architecture, especially in Persia, where it was invented, the *squinch* was often disguised by a succession of corbelled stalactite-like structures known as *muqarnas* (*see* fig. 2.3) (Pirniya and Bozorgmehri, 1990).

2.3 A Brief Historical Outline of the Origin and Developments of the Western Domes

The dome seems to have developed as roofing for circular mud-brick huts in the 14th century B.C. The Mycenaean Greeks built tombs roofed with steep corbelled domes in the shape of pointed beehives (tholos tombs) (fig. 2.4). Otherwise, the dome was not important in ancient Greek architecture (Huerta, 2007).

Figure 2.4: Primary samples of the corbelled vaults; ***a)*** *Ugrit Gorbel palace, France;* ***b)*** *Culvert of the Arkadiko bridge, Mycenae.*

The Romans developed the masonry dome in its purest form, culminating in the Pantheon which is a temple built (118–28 A.D.) by the emperor Hadrian. Set on a massive circular drum 6 m (20 ft) thick that covers eight interlocked masonry piers, the coffered dome rises 43 m (142 ft) to form a perfect hemisphere on the interior, with a large oculus (eye) in its center to admit light (*see* fig. 2.5) (Ward-Perkins, 1981).

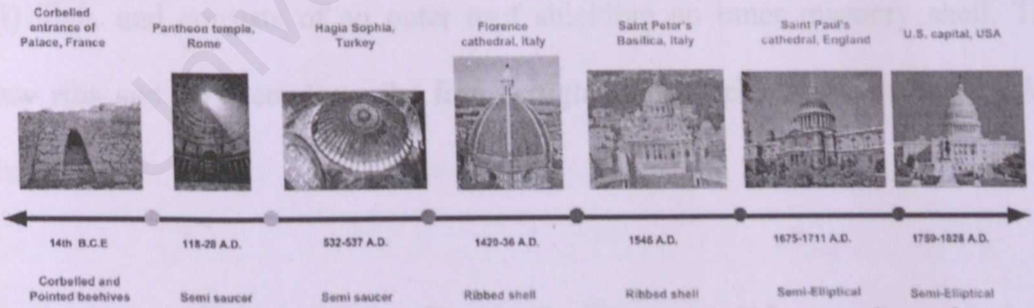


Figure 2.5: Evolution of the Western domes according to the historic chronology (Compiled by Maryam Ashkan).

The use of domes was continued in the Early Christian period for relatively small circular structures such as mausoleums and baptisteries. A typical example is the Church of Santa Constanza (ca. 350 A.D.) at Rome, originally the tomb of Constantia, daughter of the emperor Constantine the Great. Byzantine architects were far more inventive in their use of domes (Ward-Perkins, 1981).

In the Byzantine capital of Constantinople, a succession of large domed churches reached its zenith in Hagia Sophia (Church of the Holy Wisdom) which was built around (532–37 A.D.) for the emperor Justinian I. Its shallow dome, 31 m (100 ft) wide and ringed with windows at its base, is supported on four *pendentives* (spherical triangles) backed by enormous exterior piers and by a series of semi-circular domes (Ward-Perkins, 1981).

After the fall of Constantinople (1453 A.D.) to the Ottoman Turks, Hagia Sophia was converted to the mosque and later on, became the model for various types of domed mosques built throughout the Ottoman Empire in subsequent centuries.

i. Renaissance, Baroque, and Neoclassical Domes

The first great Italian Renaissance dome was the majestic octagonal dome built (1420–36 A.D.) by the architect Filippo Brunelleschi for Florence Cathedral. The immense structure, 39 m (130 ft) in diameter and 91 m (300 ft) tall, is topped with a lantern 16 m (52 ft) high, and consists of an outer roof shielding an inner masonry shell. The 8 primary ribs and 16 secondary ribs form a tightly interlocked masonry cage (Ward-Perkins, 1981).

In Rome the rebuilding of Saint Peter's Basilica occupied several generations of Renaissance architects. A plan for a Greek-cross (equal-armed) church, with a monumental dome over the crossing, was finally begun (1546) under the supervision of Michelangelo. The church's awesome multi-ribbed dome, which is 41.7 m (137 ft) in diameter, became the prototype for domes throughout the world (Martin, 1977).

The most notable baroque domes in northern Europe were built in Paris and London. Jules Hardouin-Mansart built (1676–1706 A.D.) the resplendent Church of Saint Louis des Invalides in Paris. Its dome (28 m/92 ft wide) is set on two unusually tall drums pierced with large windows that flood the interior with light. Sir Christopher Wren's noble dome for Saint Paul's Cathedral (1675–1711A.D.), London, incorporates a shallow inner dome, a conical masonry shell supporting the high lantern, and an outer lead-sheathed dome of timber (Huerta, 2006).

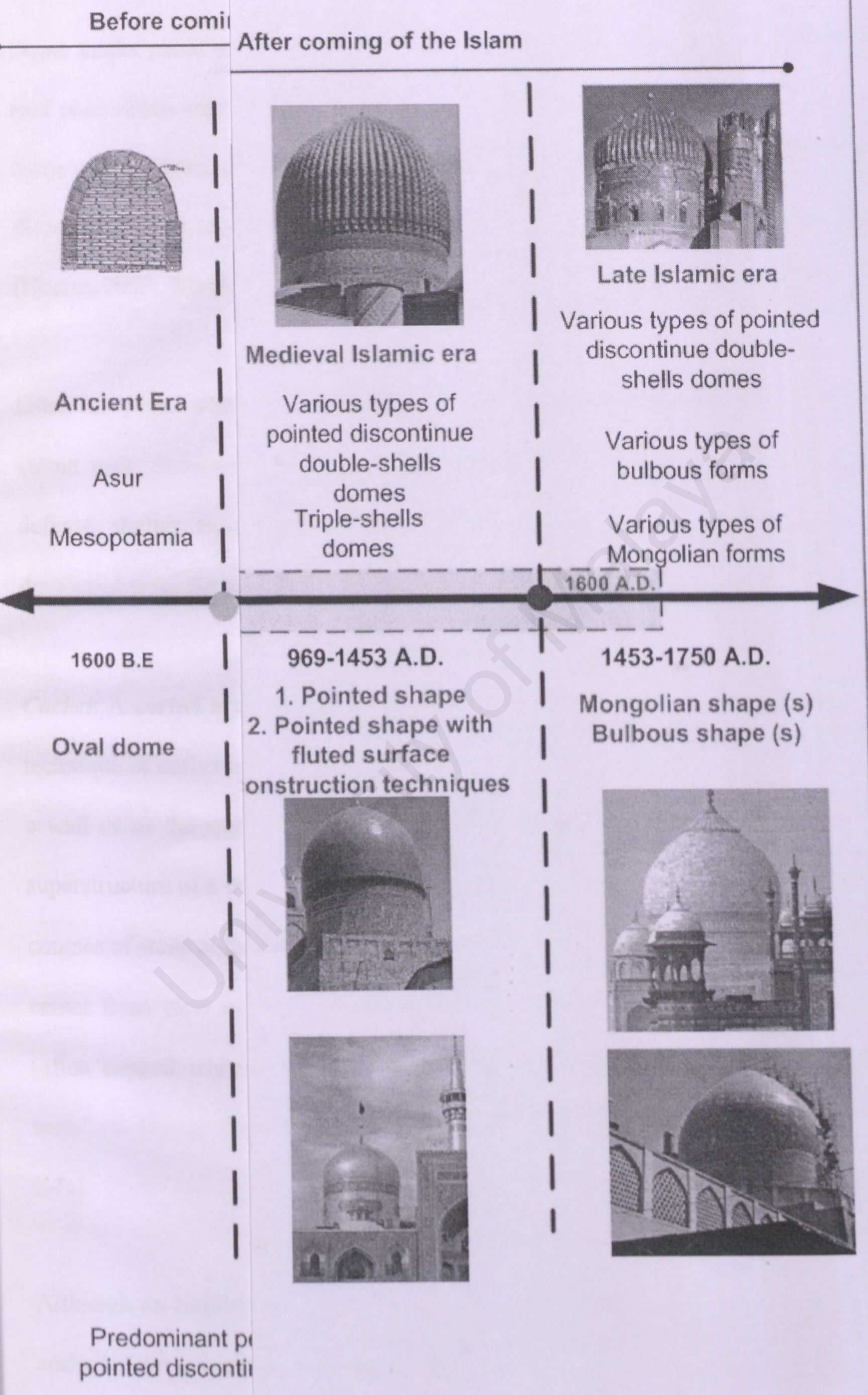
The 1792 competition for the design of the U.S. Capitol in Washington, D.C., was won by an amateur architect, Dr. William Thornton (1759–1828 A.D.), whose scheme called for a central block topped with a hemispherical dome (like that of the Roman Pantheon) flanked by two legislative wings. After this structure was burned by the British in 1814, the architect Benjamin Latrobe planned its reconstruction, which was finally finished under Charles Bulfinch's direction in 1830.

Thomas U. Walter (1804–87A.D.) was commissioned to enlarge it in 1850 A.D. Dominating the sprawling white marble building and the city's skyline is Walter's soaring cast-iron dome, 27.4 m (92 ft) in diameter (completed in 1863 A.D.), which has served as the model for many state capitol buildings. Another neoclassical example is the domed Rotunda created between 1817 and 1825 by the American statesman and architect Thomas Jefferson for the University of Virginia in Charlottesville (Martin, 1977).

2.4 Historical Outline of the Origin and Developments of Eastern Domes

It has generally been recognized that domes (either as single domical buildings or as cupolas in larger complexes of buildings) have played a significant role in development of Eastern architecture both before and after the appearance of Islam. As was mentioned in the sub- heading 2.1.1 (dome symbolism), their symbolism ideologies such as, divine, royal and celestial meanings of these domical traditions led to the popularity and monumental use of the domical shape in India and the late Roman Empire (Pope, 1971), then in the Christian and Sassanian East, and later in the Islamic Eastern lands.

The developments of the Eastern domes according to the historic chronology basically consist of two specific parts: before and after the appearance of Islam (*see* fig. 2.6) (Memarian, 1988). The origin and historical developments of the Eastern domes would be elaborated based on the following provided chronological time line.



Before comi
After coming of the Islam
Ancient Era
Asur
Mesopotamia
1600 B.E
Oval dome
Medieval Islamic era
Various types of pointed discontinue double-shells domes
Triple-shells domes
969-1453 A.D.
1. Pointed shape
2. Pointed shape with fluted surface
onstruction techniques
Late Islamic era
Various types of pointed discontinue double-shells domes
Various types of bulbous forms
Various types of Mongolian forms
1600 A.D.
1453-1750 A.D.
Mongolian shape (s)
Bulbous shape (s)
Predominant p
pointed disconti

2.4.1 Historical Background of the Eastern Domes Before the Coming of Islam

Dome vaults made possible construction beyond whether the orthogonal or rectilinear roof plan which creating high and clear spaces with open floor plans. The first known dome constructions, dating back to fourteenth and twelfth centuries B.C., are located in disparate regions around the world in what is today Egypt, China, and Mesopotamia (Huerta, 2007; Wanda, 2002).

Often integrated with the natural terrain, these ancient structures were constructed from cutout rock, stone or sun-dried mud, and had funerary or utilitarian purpose such as defense, shelter, storage and kilns. It seems likely that true arches, vaults and domes developed from the use of corbels (Smith, 1971; fig. 2.7).

Corbel: A **corbel arch** is an arch-like construction method which uses the architectural technique of corbelling to span a space or void in a structure, such as an entranceway in a wall or as the span of a bridge. A **corbel vault** uses this technique to support the superstructure of a building's roof. A corbel arch is constructed by offsetting successive courses of stone at the spring line of the walls so that they project towards the archway's center from each supporting side, until the courses meet at the apex of the archway (often capped with flat stones) (Michael, 1987). For a corbelled vault covering the technique is extended in three dimensions along the lengths of two opposing walls (fig. 2.7a).

Although an improvement in load bearing efficiency over the post and lintel design, a corbelled arch is not entirely a self-supporting structure, and it is sometimes termed a "false arch" for this reason. Unlike "true" arches, not all of the structure's tensile stresses caused by the weight of the superstructure are transformed into compressive stresses. Corbel arches and vaults require significantly thickened walls and an abutment of other stone or fill to be neutralized the effects of gravity, which otherwise would tend to collapse each side of the archway inwards (Michael, 1987).

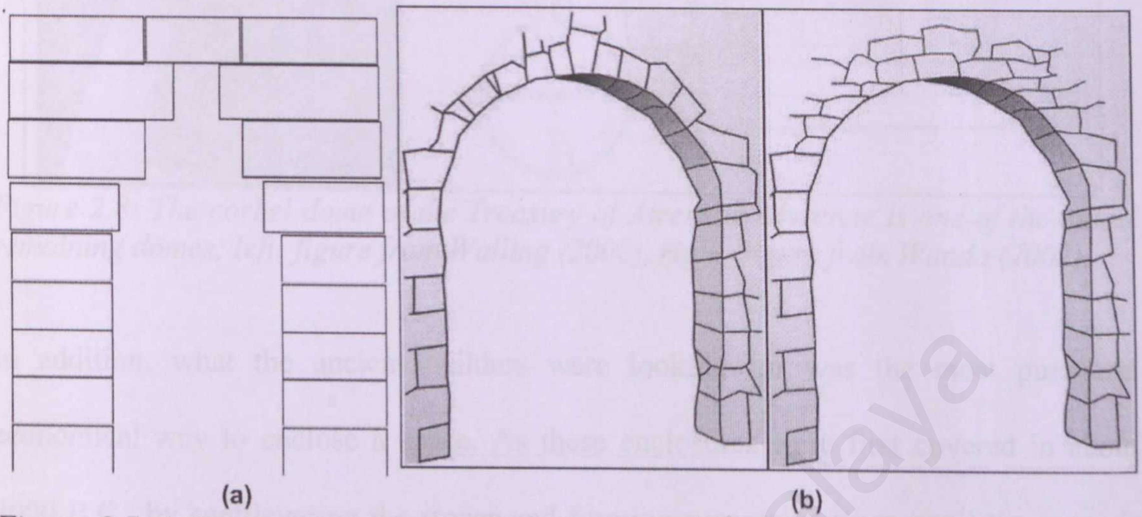


*Figure 2.7:**a)** Basic principle of corbelled arch design; **b)** Comparison of (right) a corbel arch and (left) a generic "true" stone arch (Michael, 1987).*

The projecting stones are cantilevers of short span, so that those corbels above the opening are subject to tension. This form of construction is the best known from the subterranean domed tombs which were constructed during the pre-Hellenic Minoan civilization of Mycenae, 1200 B.C. (Cowan, 1977). However, their method origin is more ancient; a small corbelled dome has been found inside the Bent Pyramid, which was built during the Fourth Egyptian Dynasty, about 2900 B.C., and in more recent tombs in both Egypt and Mesopotamia (Wanda, 2002).

In this regard, another sample of the first known domes is the Treasury of Atreus, Mycenae (1325 B.C.) with its corbel construction features and the oval shape. Its masonry courses are dry laid in concentric rings from the base to crown with horizontal bed-joints and vertical bed joints without centering (Wanda, 2002; fig. 2. 8).

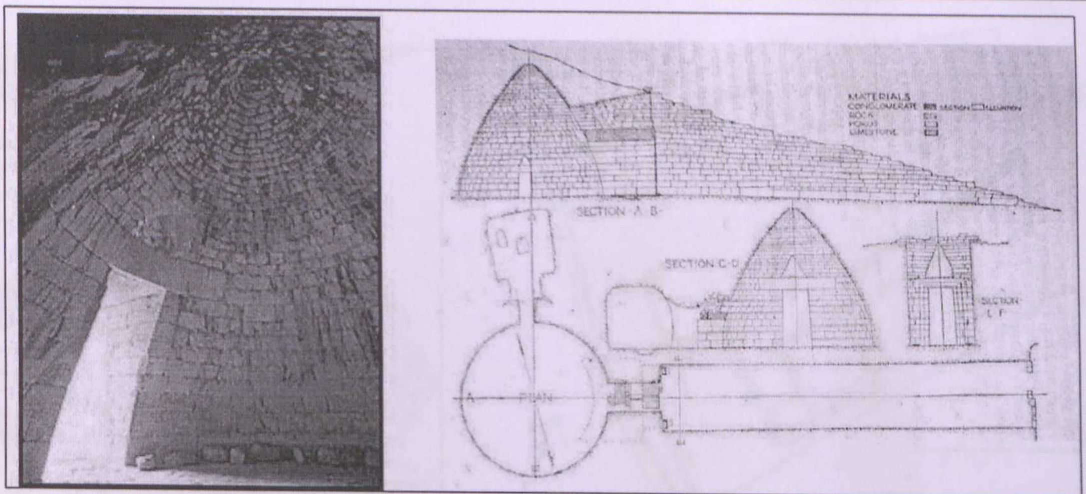


Figure 2.8: The corbel dome of the Treasury of Atreus in Mycenae is one of the oldest remaining domes; left: figure from Walling (2006), right: figure from Wanda (2002).

In addition, what the ancient builders were looking for was the most pure and economical way to enclose a space. As these enclosures were first covered in about 4000 B.C., by cantilevering the stones and forming successive rings, until the space is closed at the top. They could create what we now call a "false dome" (Cowan, 1977). Figure 2.9 shows the most ancient remains discovered so far in Asia Minor .

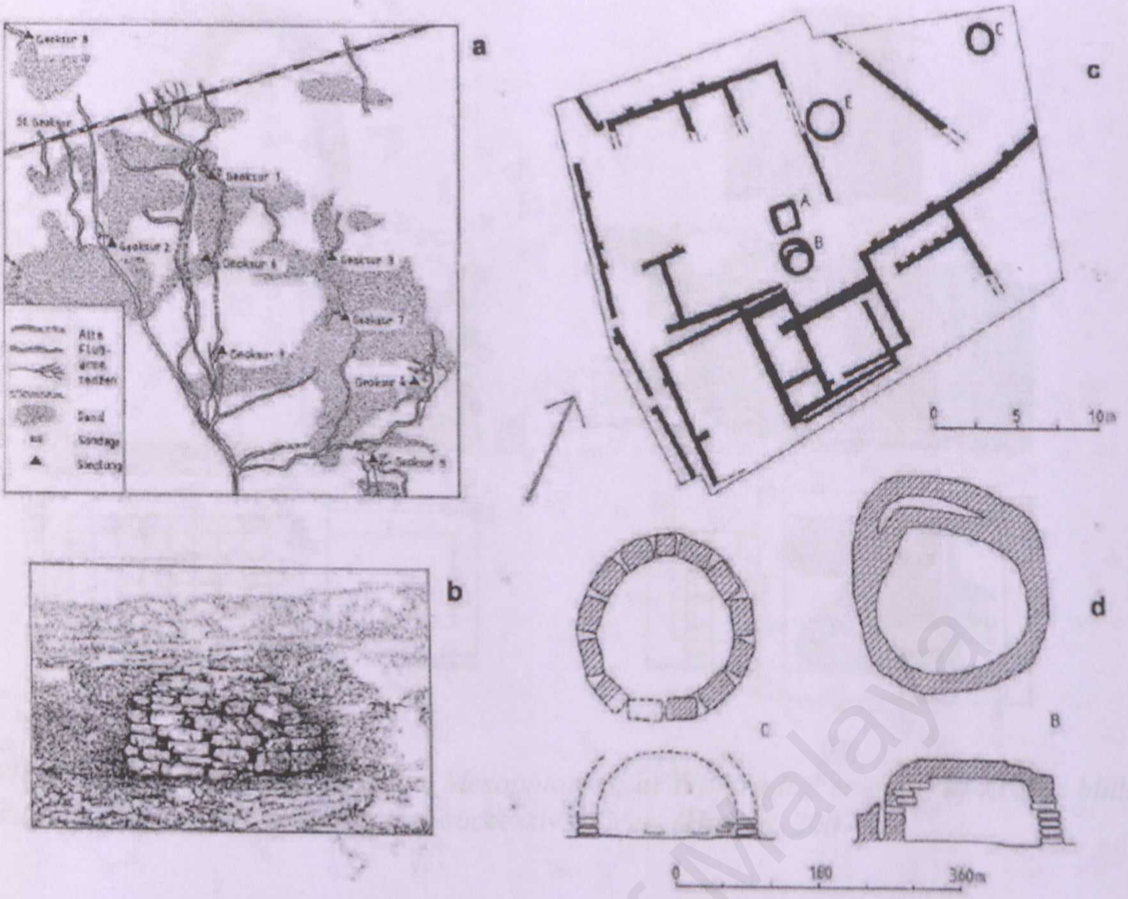


Figure 2.9: The first domes covering a closed oval plan in Asia Minor ca. 4,000 B.C. (Huerta, 2007).

Nevertheless, oval arches and domes involve as parts of the tradition of masonry buildings from the very beginning of the invention of the arch. The approximately egg-shaped forms were made regularly through the use of practical geometry, about 2000 B.C., when the dimensions and the importance of their constructions were required (Huerta, 2007; fig. 2. 10).

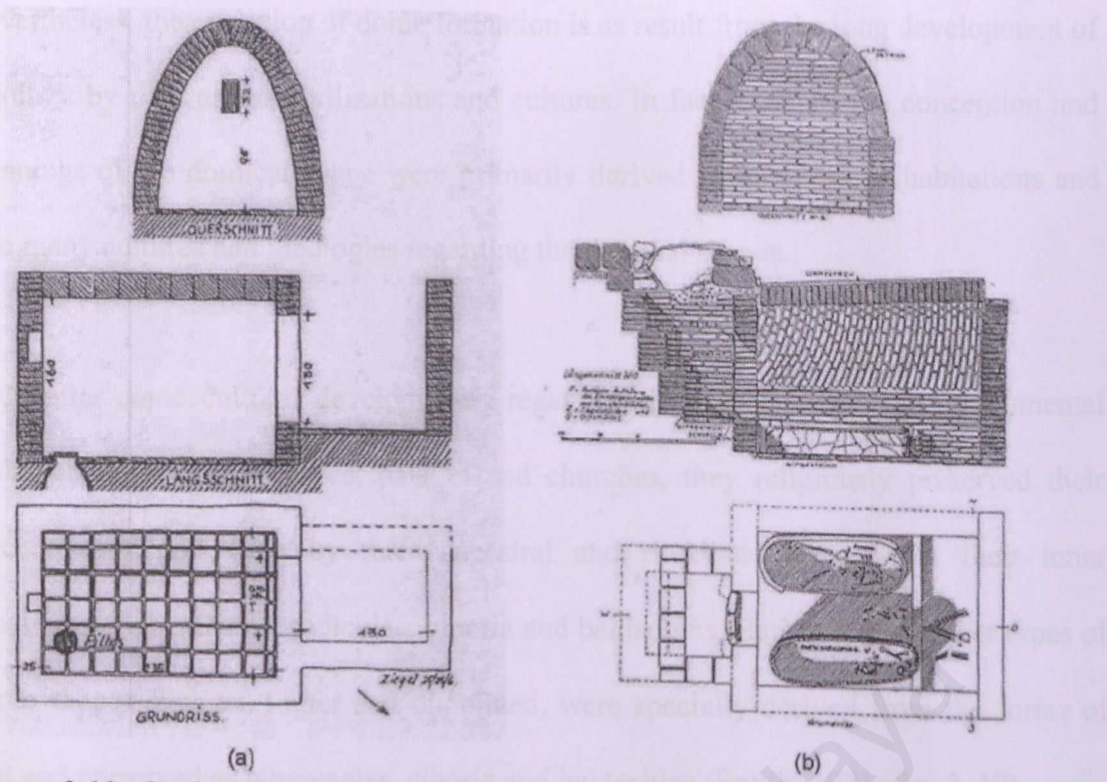


Figure 2.10: Oval arches in Asur, Mesopotamia; ***a)*** *With radial centers;* ***b)*** *Arches built without centering, by constructing successive slices (Huerta, 2007).*

In addition, domes were used to form "stone huts" and the technique was developed, no doubt, in the context of permanent settlements associated with agriculture (fig. 2.11).

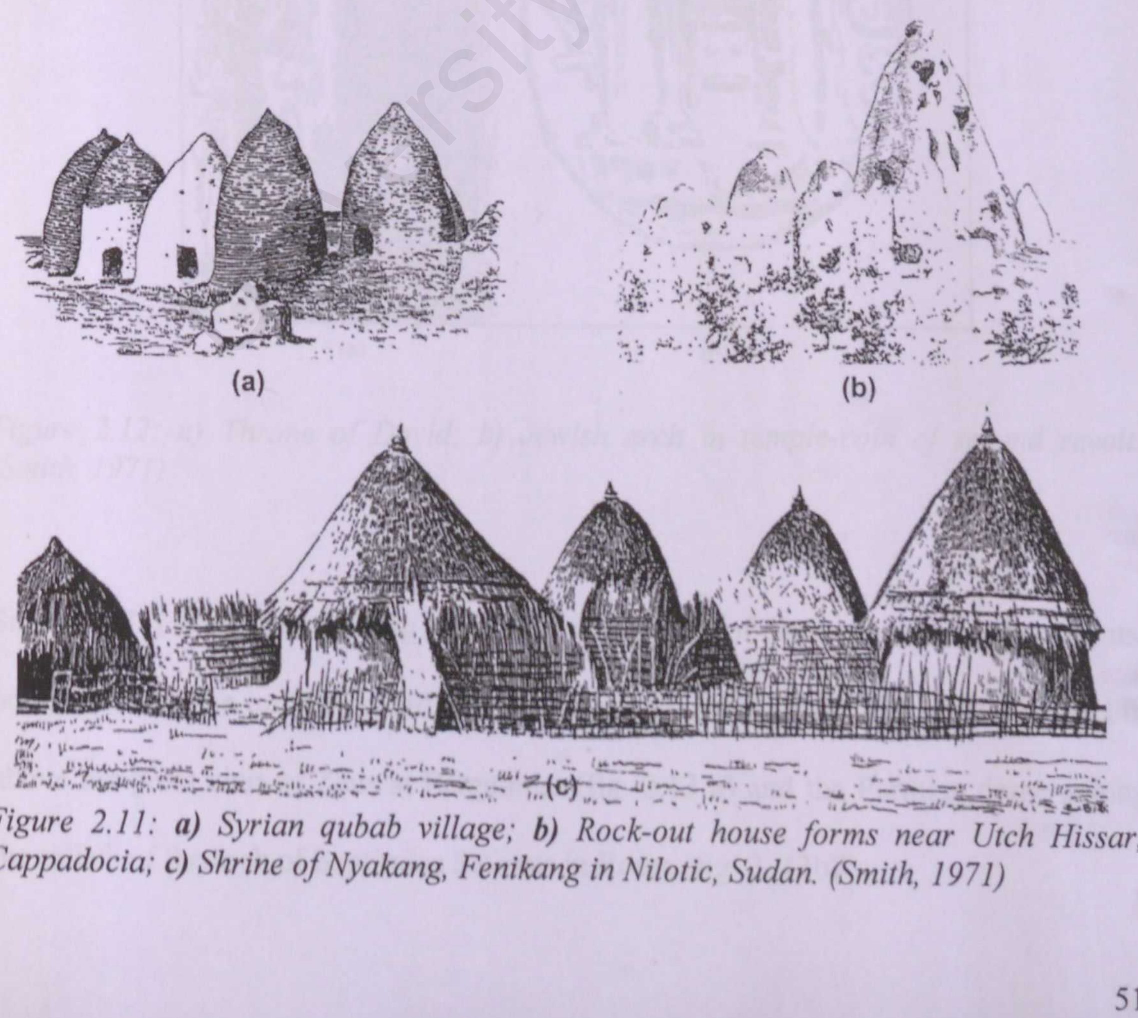


Figure 2.11: ***a)*** *Syrian qubab village;* ***b)*** *Rock-out house forms near Utch Hissar, Cappadocia;* ***c)*** *Shrine of Nyakang, Fenikang in Nilotic, Sudan. (Smith, 1971)*

Nevertheless, the evolution of dome formation is as result from the long development of ideology by the various civilizations and cultures. In fact, because the conception and meanings of the domical shape were primarily derived from primitive habitations and also many cultures had ideologies regarding the domical shapes.

Even after some cultural developments regarding erections of masonry monumental architecture such as, temples, palaces and churches, they religiously preserved their prior shapes, following by their ancestral and ritualistic shelters for their inner sanctuaries, tabernacles, aediculae, ciboria and baldachins (Smith, 1971). Other types of dome shapes such as, flatter and unpointed, were specially derived from the forms of tent and preserved as tabernacles, ciboria and baldachins (Smith, 1971; fig. 2. 12).

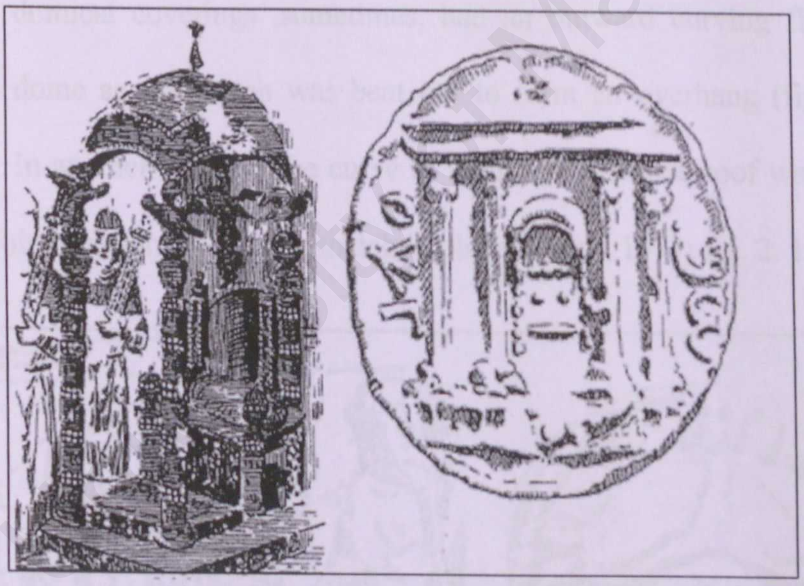
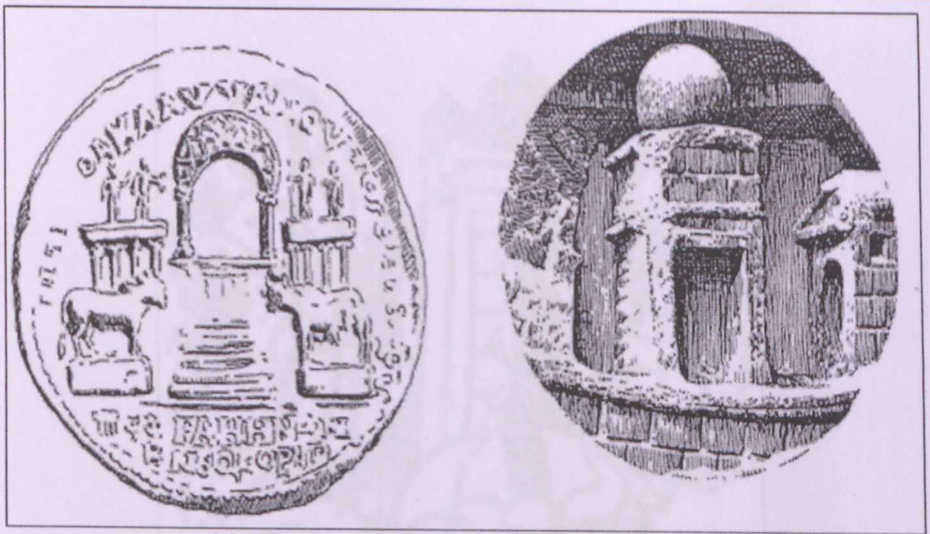

(a) (b)

*Figure 2.12: **a)** Throne of David; **b)** Jewish arch in temple-coin of second revolt. (Smith, 1971)*

Smith (1971) stated that "Owing to the light framework of the roof, forms of these tents, however, could be puffed-up and bulbous, as are shown in both the celestial baldachin above the great altar of Zeus at Pergamum (fig. 2.13 a) and the Parthian dome among the reliefs of the arch of Septimius Severus in Rome (fig. 2. 13b)".



(a) (b)

*Figure 2.13: **a)** Altar of Zeus, Pergamum, coin of Septimius Serverus; **b)** Parthian Cosmic house, throne room of fire temple, relief on arch of Septimius Serverus, Rome (Smith, 1971).*

In Syria and other parts of the Roman Empire, there were sacred plain shelters whose ritualistic and domical coverings ,sometimes, had an outward curving flange at the bottom of the dome as the thatch was bent out to form an overhang (fig. 2.14a, b) (Smith, 1971). In another example the curve of their light domical roof was broken by the horizontal bindings which held the thatch in place (Smith, 1971; fig. 2. 15).

(a) (b)

*Figure 2.14: **a)** Domical shrine of Tyche, Damascus, coin of Domna; **b)** Woman at tomb, ivory Pyxis. (Smith, 1971)*

Figure 2.15: Woman at tomb, Ivory Pyxis. (Smith, 1971)

Wooden domes were the common domical techniques in the Near East, especially, in Syria. Grabar (1963) demonstrated from literary sources that the octagonal churches of Antioch, Nazlanzus and Nyssa had wooden roofs.

Although, both Smith (1971) and Grabar (1963) repeatedly pointed out the possible influences of wooden prototypes upon the stone architecture of Armenia and suggested certain wooden derivations for the Asiatic adjustment of the dome to a square plan. They always came back to their undemonstrated conviction that the dome itself originated in the brick architecture of Mesopotamia and Iran. Smith (1971) insisted that the Early Christian churches of Syria had wooden domes, any how and they were taken over by the Arabs for their mosques.

In 1940, Creswell, in his study of the celestial symbolism of the dome, cited much of the evidence for the importance of the wooden dome in Etruscan and Roman architecture and suggested that it might also used in ancient Greece. As early as 1996, Petersen wrote: "*In Syria wood was throughout antiquity the specific material for ceilings*"

Additionally, it is said that the great Syrian domes of Bosra, Jerusalem and Damascus, all of wood, were constructed as double cupolas with an elaborate system of girders and ribs which were results from acquired experience in shipbuilding (Smith, 1971).

Unsuccessful Early archaeologists' efforts minimized the importance of the dome in Syria and Palestine because they found so few remains of masonry vaults on churches of the central type. In fact, they disregarded the possibilities of wooden dome constructions because majority of Syria and Palestine was thought to have been barren and timberless (Smith, 1971). Even the acknowledged use of great timbered roofs on both the pagan and Christian temples may definitely demonstrate that acquaintance with existing of abundant timbers were plentiful in the Lebanese mountains; whereas forests ,which are known to have existed North of Hebron and in the region of Lake Tiberius, did not precedence the emerging testimony of stone roofs in the Hauran and the unquestioned conviction that domes were primarily form of vaulting (Pope, 1971).

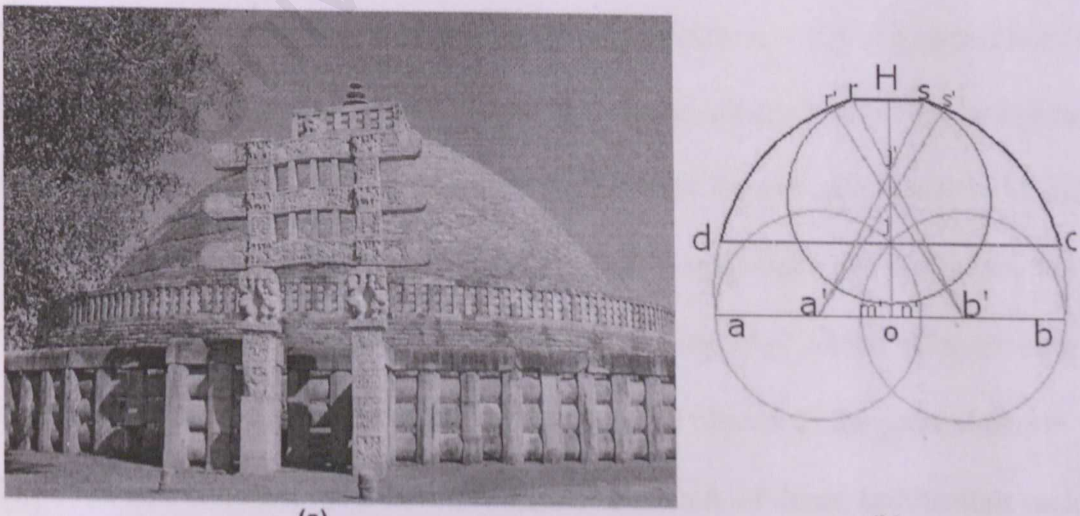
Apart from the variety of historical texts, there emerge certain domical samples in which their considerations increasingly manifest the steps of the evolution of Eastern domes over decades. In this manner, four dominant examples may be listed as follows: Sanchi stupa, Nyssa domical hall, Basilica of Hagia Sophia, and the Sassanids' famous palace of *Ardeshir*.

In addition to the appearance of Buddhism, apt samples of the relationship between logical thoughts and dome symbolism were manifested through constructions of

Buddhism temples such as, the Sanchi Stupa, in the third century B.C.E. It is considered as the primary emerged sample of domes in Asia (and also is comparable with the Pantheon in Italy).

i. The 'Great Stupa' at Sanchi: was originally commissioned by the Emperor Ashoka the Great in the third century B.C.E. Its nucleus was a simple hemispherical brick structure built over the relics of the Buddha. It was crowned by the *chhatra*[1], a parasol-like structure symbolizing high rank, which was intended to honor and shelter the relics.

This domical form was flattened near the top and crowned by the *chhatra* (fig. 2.16a). Its curvature shape was set on a high circular drum meant for circumambulation, which could be accessed via a double staircase (Dehejia, 1992). In fact, Stupas are large-scale memorials constructed in particularly holy places. Generally, they enshrine relics of some sort. As a building type the *Stupa* is the forerunner of the pagoda. However, the *Stupa* has also come to be known, on a smaller scale, as the reliquary itself and can be made of crystal, gold, silver or other precious metals (Dehejia, 1992).



(a) (b)

*Figure 2.16: **a)** Exterior view of Sanchi Stupa, India (Source: www.flickr.com/photos/35849460@N00/38260357/); **b)** The derived geometrical design of Stupa.*

[1] *Chhatra* is the precious parasol umbrella, which is used as an auspicious symbol in Indian religions (Dehejia, 1992).

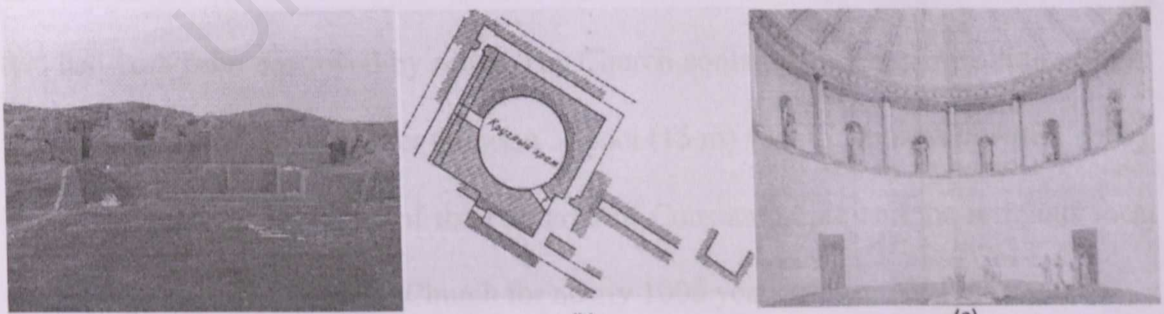
The Great *Stupa* of *Sanchi* underwent a complete reconstruction after wanton damage inflicted upon it in the middle of the second century B.C.E. The reconstruction consisted of a stone casing, a terrace with a double flight of steps, balustrades, a paved processional path and an umbrella and railing which all were built of sandstone. Four elaborately carved gateways were added in the first century B.C.E (Dehejia, 1992). The last addition took place during the rule of the Guptas, sometime before 450 AD. By now effigies of the Buddha were permitted and four stone Buddhas were placed against the walls of the *stupa* facing the gates. Their haloes are elaborately carved.

In a larger sense, the *stupa* embraces also as cosmic symbolism. Its hemispherical shape symbolized as the world egg. This is a recurrence of the symbolism whereby Earth supports Heaven and Heaven covers Earth. The axis of the world is always represented in the *stupa*, rising above its summit (Kentish, 1997). The so-called "parasols", set one above the other along the shaft emerging from its uppermost region, show a heavenly hierarchy. The cosmic symbolism is completed by a ritual circumambulatory path around the monument (Dehejia, 1992).

Despite its simplified shape, complex geometrical calculations used to be established for this kind of dome analysis. While it looks like a semi-spherical form according to its conceptual form (as can be seen above), its geometrical form is appropriate to be called "saucer". It is governed by intersecting two circular arcs which are cut on the top by crossing a horizontal line regarding to the rest of *chhatra* (fig. 2.16b). Domical form of this *Stupa*, however, does not mainly possess integrant objects of the present domes, but it has been characterized by the several distinct elements of dome architecture such as, drum, rotunda base form, and imitation of hemispherical shape for the religion architecture. Later on, such certain philosophic shape and form were employed to represent the meaning of universe in the architectural form.

ii. Nyssa domical hall: The second and most important sample is a large (17 meters in diameter) domical construction, probably of the first century A.D. excavated in the Parthian capital at Nyssa.

Nyssa, the capital of the Parthian empire is now one of the 5 World Heritage sites in Turkmenistan. According to anthropological point of view, the Parthians were nomadic tribes from the North West of Iran. The Parthians were under the influence of Greek culture in their architectural style and school of sculpturing (Grabar, 1963). Nyssa domical hall was built within two concentric city walls surrounded by a moat; Nysaa had a water system that fed by nearby mountain. The administrative buildings were multi-functional. There was a treasury, a circular building which could have been a Zoroastrian temple. Its spatial space consists of a hall with 4 columns in the center and niches for statues on the wall (Ayatollahi, 2003; fig. 2. 17a).



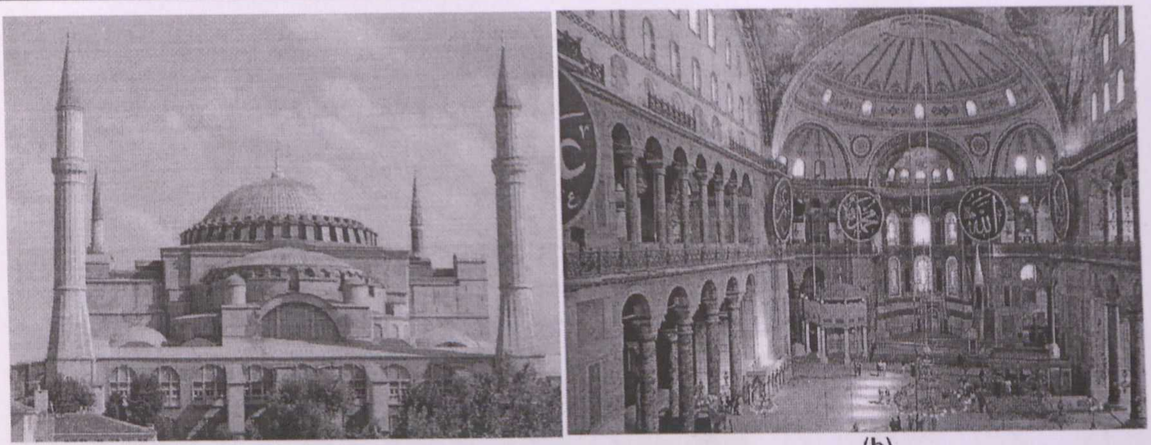
(a) (b) (c)

Figure 2.17: a) Capital of the Parthian empire, Nyssa, 3rd cent A.D. (Source: www.flickr.com/photos/johnstam/2240857227/); b) Plan of the circle hall, Nyssa (Grabar, 1963); c) Reconstruction of circular hall (Grabar, 1963).

Its plan is a square with remarkably heavy walls and a circular central hall (fig. 2. 17b); a sort of ambulatory area surrounded most of this hall. The small entrance corridor suggests that this type of building was still fairly unfamiliar to the architects of that time (Grabar, 2006). However, the massive brick walls remained a characteristic of much of later Iranian architecture and also the reconstructed elevation (fig. 2.17c) shows an impressive conception of its interior space.

The main purpose of the building is uncertain; it may have been a temple or a *tropain* celebrating the victory of the Parthians over Rome. Regardless of its construction purpose and of the validity of details of reconstruction, the interest of this dome is that it exposes the existence of a monumental domical tradition in Central Asia (Grabar, 1963).

iii. Hagia Sophia Basilica or Ayasofya Museum: is a former patriarchal basilica, later a mosque, now a museum in Istanbul, Turkey. Famous in particular for its massive dome, it is considered the epitome of Byzantine architecture. It was the largest cathedral in the world for nearly a thousand years, until the completion of the Seville Cathedral in 1520 (Altin, 2001). The current building was originally constructed as a church between A.D. 532 and 537 on the orders of the Byzantine Emperor Justinian, and was in fact the third *Church of the Holy Wisdom* to occupy the site (the previous two had both been destroyed by riots). The Church contained a large collection of holy relics and featured, among other things, a 50 foot (15 m) silver iconostasis (Altin, 2001). It was the patriarchal church of the Patriarch of Constantinople and the religious focal point of the Eastern Orthodox Church for nearly 1000 years (Altin, 2001).



(a) (b)

Figure 2.18: The Hagia Sophia museum, Turkey ***a)*** *Exterior View (Source: www.ancienthouse.net/?s=hagia+sophia);* ***b)*** *General interior view of the Hagia Sophia (Source:www.sacred-destinations.com/turkey/hagia-sophia-photos/slides/nave-general-view.htm).*

In 1453, Constantinople was conquered by the Ottoman Turks and Sultan Mehmed II ordered the building to be converted into a mosque. The bells, altar, iconostasis, and sacrificial vessels were removed, and many of the mosaics were eventually plastered over. The Islamic features (such as the *mihrab*, the *mimbar*, and the four minarets outside) were added over the course of its history under the Ottomans (Altin, 2001). It remained as a mosque until 1935, when it was converted into a museum by the Republic of Turkey (fig. 2.18).

It is unquestionably one of the finest buildings of all time. In fact, it is deemed as a primary example of saucer dome typologies (fig. 2.19a). Between the years 537 and 1453, the building was used as a church. From 1453 to 1935, it was used as a mosque. In 1935, it was turned into a museum by Atatürk and has been used as a museum since then (Altin, 2001).

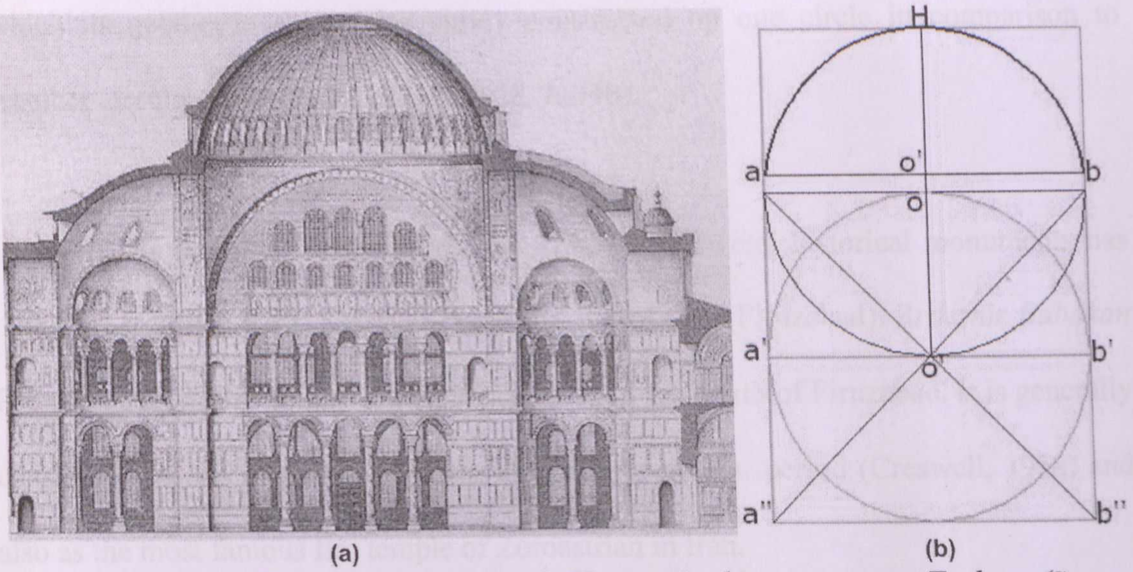


*Figure 2.19: **a)** The cross-section of Hagia Sophia museum, Turkey (Source: www.grandtradition.net/hagia-sophia); **b)** Derived geometrical design of its cross-section.*

The architects Anthemios and Isidoros wanted to cover the basilica's roof with an unusual way of covering without using wood beams. Hagia Sophia is therefore important as the first example of this kind in the world. This large dome in the middle of the building is not circular. Its base shape likely was circular and this shape had been changed after several damages and the repairs. Its one diameter is 30.876 meters and the other is 31.877 meters, which gives an average of 31.37 meters and its rises 55.60 meters above the ground (Altin, 2001). This building has commonly been investigated by Western scholars because of its influence on the Western domical structures.

The enormous dome of Hagia Sophia rests on the four *pendentives* forming a square as transition items. This magnificent dome is supported by four great arches resting upon the four massive piers in the middle of the building, which are primary examples of *pendentive* method constructed for the transformation purpose in the dome construction. The frame of its skin is constructed of 40 brick ribs and 1.10 meters in width (Altin, 2001). It is considered as the last example of *pendentives*, which had been built in Asia and never would be replicated again later on. Semi-circular design of this dome not only possess a complex formula, but it may also consider as the only sample in the East in which its geometric shape was purely constructed on one circle in comparison to whether circulars or elliptical domes, (fig. 2. 19b).

***iv. Sassanids' famous palace of Ardeshir*:** Several historical monuments has remained from the early Sassanid era in the city of Gur (Firuzabad). *Ardeshir Babakan* Palace or Sassanians' big fire-temple is located in the North of Firuzabad. It is generally considered as one of the magnificent monuments of this period (Creswell, 1958) and also as the most famous fire temple of Zoroastrian in Iran.

Ibn Istakhri, an Iranian Muslim historian, mentions this site as a fire temple of great importance built during the Sassanid dynasty 9Memarian, 1988). Other scholars, historians, and archeologists believed that this site should be Ardeshir palace, the founder of the Sassanid Empire, which was erected during the late Parthian or the early Sassanid times (Pope, 1971).

The palace of Ardeshir overlooks a small lake fed by a rich spring water. The main entrance *iwan* of the palace enjoys the view of the lake and its vicinity. It is believed that a Persian style garden enclosed both palace and related lake (Ayatollahi, 2003). The *iwan* or arched entry was a building innovation of the later Parthian era which is found predominantly in Sassanian palaces and important buildings. One can still see older homes in Firuzabad and nearby towns using the *iwan* as a main entrance overlooking the garden. The Sassanid style *iwan* is usually constructed between two halls as supporting elements of the *iwan* hall. In addition, such a style became more popular in the other Sassanid palaces built in Kazerun, Qasr Shirin, Sarvestan and Damghan (O'Kane, 1998).

(a) (b) (c)

*Figure 2.20: **a)** Ardeshir palace and big fire temple, Iran (Source: Maryam Ashkan); **b)** Interior view of squinches (The Iranian Ministry of the Cultural Heritage (ICHO)); **c)** Typical derived geometrical design of domes (Pirniya and Bozorgmehri, 1990).*

Architecturally, this monument is composed of several roofed platforms and a number of rooms and numerous halls. This structure contains three domes, which have been made a bit larger and more magnificent than other samples of this era (fig. 2. 20a). What is particularly interesting in this palace is that its architectural design does not exactly categorized whether into the Parthian or even Sassanian styles; In fact, its design is a unique design of architects of Fars. The structure measure is 104 m (340 ft) by 55 m (180 ft) and was built of local rocks and mortar with plasterwork on the insides (O'Kane, 1998). Its huge semi-ellipse domes and *squinch* technique of transition tier distinguish its construction style from other samples of this era (fig. 2. 20b).

The throne room is a majestic room almost as high as a three stories building. Remaining plaster works on the walls depict the use of Achaemenian patterns. This rather large monument is made of stone and has three domes with many rooms. The ornaments and carvings on top of the interior doorways are similar to those in Takht-e-Jamshid (Persepolis). This palace has been registered on the list of Iran's National Historical Sites. After the coming of Islam, dome architecture underwent rapid evolution in terms of the need of building many mosques and tomb edifices and also, increasing the spiritual meaning of the dome in architecture.

This new methodology of dome construction was introduced for the erection of huge monuments topped with various domes throughout the Eastern regions. The complex geometrical framework of this particular dome rests on the three basic circles which are geometrically supported by a triangle placed at the center of this geometric composition. The height or rise of domes in this category had reached to the uppermost value than others in the East due to its exclusive proportion and geometrical formula (Grabar, 1963; Memarian and Pirniya, 2003; fig. 2.20c).

A specifically recognizable Islamic architectural style emerged soon after the time of Muhammad, developing from localized adaptations of Egyptian, Byzantine, and Persian/Sassanid architectural contexts. The Dome of the Rock (*Qubbat al-Sakhrah*) is the earliest sample of such a dome constructed at the early 691 A.D. in Jerusalem which composes of interior vaulted spaces, a circular dome, and the use of stylized repeating decorative patterns (Hillenbrand, 1999b).

2.4.2 Historical Background of the Eastern Domes After the Coming of Islam

By beginning of Islam, early Muslim architects often relied on involving symbolism in the conception of their own buildings; this symbolism is taken from their deep understanding for the Holy Quran, and their great belief in ***'Allah'*** (Blair, 1994).

As is so often the case in Islamic architecture, the regional terminologies were used to name the building functions; terms of '*qubbat*' (in Arabic countries), '*gunbad*' (in Iran and Afghanistan), '*gumbaz*' (in Uzbekistan), and '*Kumbett*' (in Turkey) are substantially referred to the most distinguishing forms of the domes in the Middle East and Central Asia (Ashkan and Yahaya, 2009).

Even before that, however, there was a long tradition of buildings topped with domes (e.g. palaces, mosques, tombs, and baths); the Dome of the Rock (completed in 691) in Jerusalem being one of the earliest examples. Set on a pillared arcade, its double dome is of timber construction. It is an Islamic shrine and a major landmark located on the Haram al-Sharif (Temple Mount) in Jerusalem (Creswell, 1940).

Its construction ordered by Caliph Abd al-Malik, half a century after the death of Prophet Muhammad (s). The rock marks the site from where Prophet Muhammad (s) made his *Miraaj* or *Night Journey* into the heavens and back to Makkah (Qur'an 17:1). The Dome of the Rock presents the first example of the Islamic world-view and illustrates the symbol of the oneness and continuity of the Abrahamic (i.e., Jewish, Christian and Muslim) faith (Creswell, 1940).

The extraordinary visual impact of the Dome of the Rock is in part because of the mathematical rhythm of its proportions. All the critical dimensions are related to the center circle that surrounds the sacred stone. For example, each outer wall is 67 feet long, which is exactly the dome's diameter and exactly its height from the base of the drum. The same principles were used in Byzantine churches of Italy, Syria, and Palestine, but none compare with the integration of plan and elevation seen in the Dome of the Rock, especially, its wooden dome which preceded those common prior traditions of wooden domes in both Syria and Palestine (Blair, 1994; Creswell, 1940).

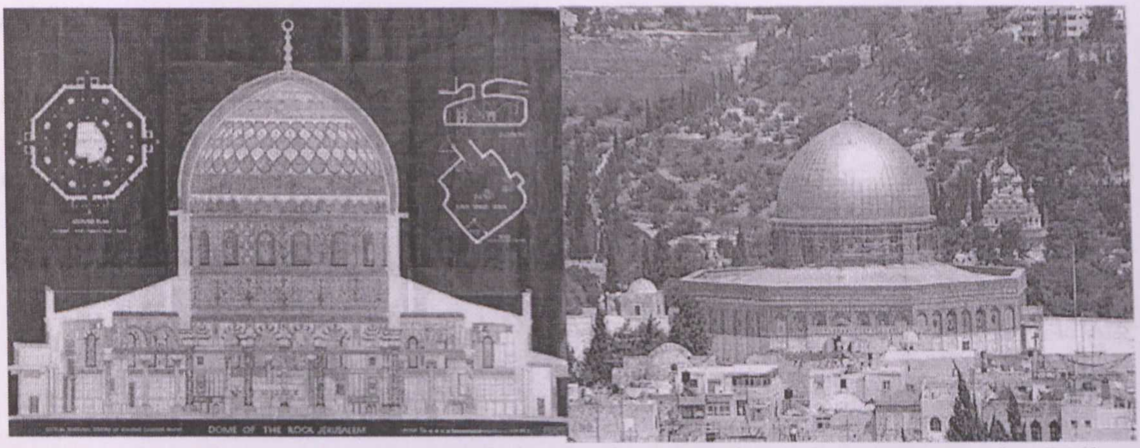


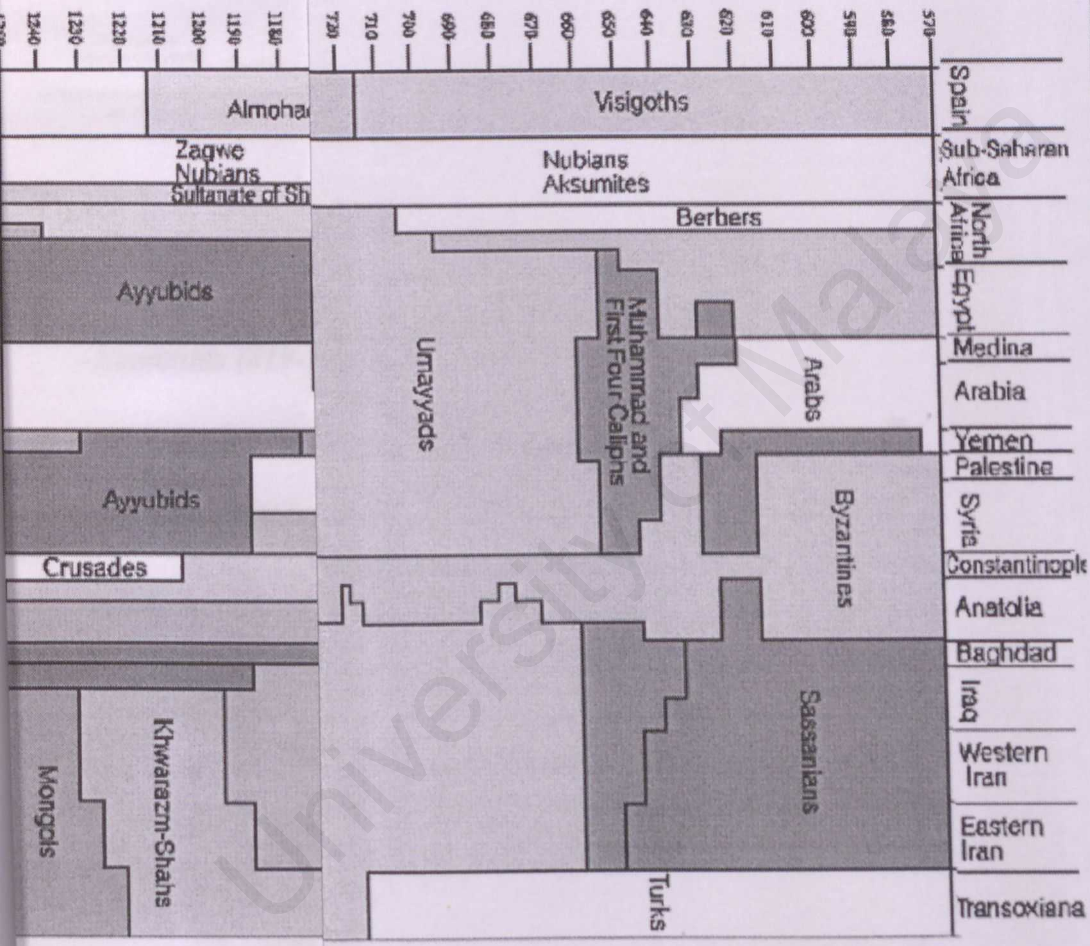
Figure 2.21: The wooden Dome of the Rock, Jerusalem, Cross-section by William Harvey, Looking South, 1909 from (www.vam.ac.uk/images/image/38317-popup.html).

Its dome span is approximately 60 feet (20 m) in diameter. Structurally, it is mounted on an elevated drum consisting of a circle of 16 piers and columns. Surrounding this circle is an octagonal arcade of 24 piers and columns (Allen, 1993; fig. 2. 21).

After the introduction of using of wooden domes in Islamic architecture, the appearance of the domed mausoleum became greater important for the rapid development of such an architectural item in the early Islamic Persia. In this regard, despite initial Islamic hostility to tomb structures, by the 10th century several had probably been built by the Abbasid caliphs for themselves (Allen, 1993). Domed tombs had also been erected over the graves of many Shi′ite martyrs (Blair, 1983), and came to pay attention by pilgrims that expedited the spread of this architectural form.

On the other hand, the overall appearance of domes during Islamic architecture reflects the wealth and power of its ruler patron. In fact, the specific evolution of dome composition and organization are a matter of socio-political concerns that were often occurred under powerful Islamic dynasties. Apart from sponsor limitation, development of construction knowledge as a result of interaction of regional science, however, can not be overlooked.

Of course, there is much more to Islamic history than these texts are able to convey; as a result, a series of most important Islamic dynasties according to the chronological list can be addressed and listed as follows: Umayyads (661-750 A.D.), Abbasids (759-1258 A.D.), Samanids (819-1005A.D.), Ghaznavids (977-1186 A.D.), Almoravids (1056-1147 A.D.), Almohads (1130-1269 A.D.), Ayyubids (1169-1260 A.D.), Seljuks (1038-1194 A.D.), Ilkhanids (1256-1353 A.D.), Mamluks (1250-1517 A.D.), Timurids (1370-1506 A.D.) , Mughals (1526-1858 A.D.), Saffavids (1501-1732 A.D.), Qajar (1779-1924 A.D.), and Ottomans (1281-1924 A.D.). However, these Islamic dynasties had spread in the distinct territories surrounding the Islamic lands from Spain to India and some of them had ruled in the Middle East and Central Asia (Bosworth, 1996). As statements below indicate, several Islamic dynasties have appeared through distinct Islamic periods (Hillenbrand, 1994; fig. 2. 22).



Spain
Sub-Saharan Africa
North Africa
Egypt
Medina
Arabia
Yemen
Palestine
Syria
Anatolia
Baghdad
Iraq
Western Iran
Eastern Iran
Transoxiana
Visigoths
Zagwe
Nubians
Nubians
Aksumites
Berbers
Ayyubids
Muhammad and First Four Caliphs
Arabs
Umayyads
Byzantines
Ayyubids
Crusades
Sassanians
Turks
Mongols
Khwarazm-Shahs
570
580
590
600
610
620
630
640
650
660
670
680
690
700
710
720
1180
1190
1200
1210
1220
1230
1240

Accordingly, only some of those dynasties played a significant role in the dome evolution over historic era. In fact, there exist four specific movements regarding the main concept of Islamic which were mainly introduced and achieved by six dynasties; These are Samanids (819-1005A.D.), Seljuks (1038-1194 A.D.), Ilkhanids (1256-1353 A.D.), Timurids (1370-1506 A.D.), Saffavids (1501-1732 A.D.), and Shaybanids (1503-1800 A.D.; fig. 2. 23).

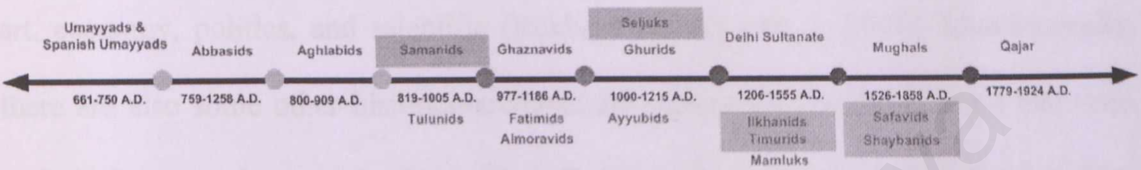


Figure 2.23: Some of the special Islamic dynasties and specific studied periods on the time line (Compiled by Maryam Ashkan).

- Samanids (819-1005A.D.): The Samanid Empire was the first native dynasty to arise in Iran after the Muslim Arab conquest. It was well-known for reviving Iranian national sentiment and learning (Memarian and Pirniya, 2003; fig. 2. 24).

Figure 2.24: Map of the Samanid Empire at its level of power.

According to Petersen (1996), in fact, the well-known process of Iranian renaissance began in the Central Asia rather than in Iran, and he sees the reason for that in the difference of the social groups in these two parts of Muslim world. In fact, the mercantile, trading society of Central Asia was much more suitable for developing an egalitarian Islamic society than the hierarchical caste society of Iran (Shahmiri, 2007). Therefore the Samanids, who were the real rulers of Transoxiana[2] could be seen as a pioneers of Iranian renaissance (Shahmiri, 2007).

Indeed the changes occurred under Samanid influences are: cultural, linguistic, social, art, economy, politics, and scientific (Bukhara History-part 7, 2007). Monumentally, there are also some other historico-architectural memorials remaining from that time, such as the mausoleum of the Samanids in Bukhara, the mausoleum of Arabato in Tim, the No Gumbad mosque in Balkh, and so on.

The Ismail Samanid mausoleum is the oldest Muslim structure in Central Asia and the oldest building made of fired bricks from the basement to top (fig. 2.25). It was built from about 907 to before 942 at Bukhara. Square in plan, with a domed roof, it was derived from the Iranian *chartaq,* namely the tetra style structure that was the Zoroastrian[3] fire temple in Sassanian times (Askarov, 2003). The arcaded galleries concealing the transition between the central dome and the four small corner domes are also a Sassanian tradition and were to become very popular in Indian architecture later (O' Kane, 1998).

[2] Is the ancient name used for the portion of Central Asia corresponding approximately with modern-day Uzbekistan, Tajikistan and southwest Kazakhstan (Pope, 1971).
[3] Is the religion and philosophy based on the teachings ascribed to the prophet Zoroaster, after whom the religion is named. The term *Zoroastrianism* is, in general usage, essentially synonymous with **Mazdaism**, i.e. the worship of Ahura Mazda, exalted by Zoroaster as the supreme divine authority (Smith, 1971).

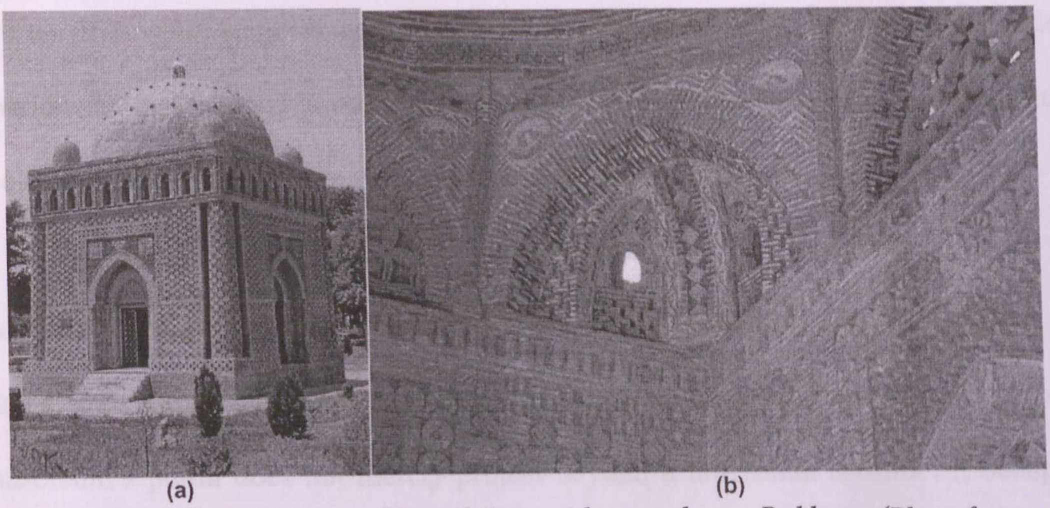


Figure 2. 25: ***a)*** *Exterior view of Ismail Samanid mausoleum, Bukhara (Photo from www.sacred-destinations.com/uzbekistan/bukhara-ismail-samani-mausoleum.htm);* ***b)*** *Interior view of its squinches (Source: www.archnet.com).*

The mausoleum can be described as a pearl in Central Asian architecture; it exposes the unity of an architectural form, construction, and abundant decorations visually. Furthermore, this unique monument considered as the main achievements of centuries of experimentation, unsurpassed craftsmanship, composition, attention to detail, and ornamentation (Shahmiri, 2007).

Its composition is strictly pivotal, that is, all four facades are identical (10.8 m x 10.8 m). The cubic building of the mausoleum is completed with a high refined arcade and cupola. The high-powered round columns, at the coins, and the light bordering of the walls, give the monument an imposing view. Its cube symbolized an ancient symbol of the earth, the personified Ka'ba in Mecca along with a symbol of the sky (a dome symbolized the Universe). Forms of mausoleum designed by the geometry of al-Khorezmi, al-Fargani and Ibn-Sina (Askarov, 2003).

The Mazar Arab Ata, or the "Shrine of the Arab Father", is a cubical, domed brick mausoleum built in 977-78 in the town of Tim in Uzbekistan's Samarkand province. The Arab Ata mausoleum was probably built in the reign of the Samanid ruler Nuh

Mansur (976 - 997) and is noted for its seminal architectural form and decoration experiments that shaped much of Central Asia's early domed square mausoleum typology (O'kane, 1998) were replicated from its configuration.

The Arab Ata mausoleum is as one of the earliest examples of the *pishtaq*, or exaggerated, projecting arched portal. Unlike latter-day *pishtaqs*, the Arab Ata mausoleum's portal does not merely project beyond a horizontal roofline; it occupies the entire front elevation and screens the dome. The inscription motifs and embroiders of rectangular frame of its portal is another innovation that became a customary motif in subsequent mausoleums, regionally. The remaining elevations were left stark, possibly to concentrate on this elaborate portal façade (Knobloch, 2001).

The mausoleum is also noted for useing of the earliest form of *muqarnas* ornament, seen as a two-stage transition from a *squinch* base to a round dome. A decorative *squinch* flanked by half *squinches* on either side cover the structural corner *squinch*. This trilobed squinch and trilobed arch motif was to become a standard in later Seljuk and Timurid architectural styles (Hillenbrand, 1999b).

However, not all of the architectural experiments of Arab Ata mausoleum were readily duplicated. For example, the tympanum features of *pishtaq* and a group of three rectangular windows are rarely seen in new structures. The mausoleum's elevations were embellished with complicated star-and-polygon patterns in brick tiles, and double-stretcher brick courses as seen in pre-Mongol brickwork of the region (Memarian and Pirniya, 2003).

By the early nine century, the No Gumbad mosque was built at the South-West of Balkh which is one of the oldest known monuments of Islam. Its modern name, No Gumbad, refers to the nine vaults or domes that topped the original structure (Hillenbrand, 1994). These domes have since fallen, and the walls and columns of the mosque are buried in more than one meter of mud-brick fragments. Because of its two remaining archways in danger of collapse, the structure is in urgent need of stabilization and restoration (Hillenbrand, 1994; fig. 2. 26).

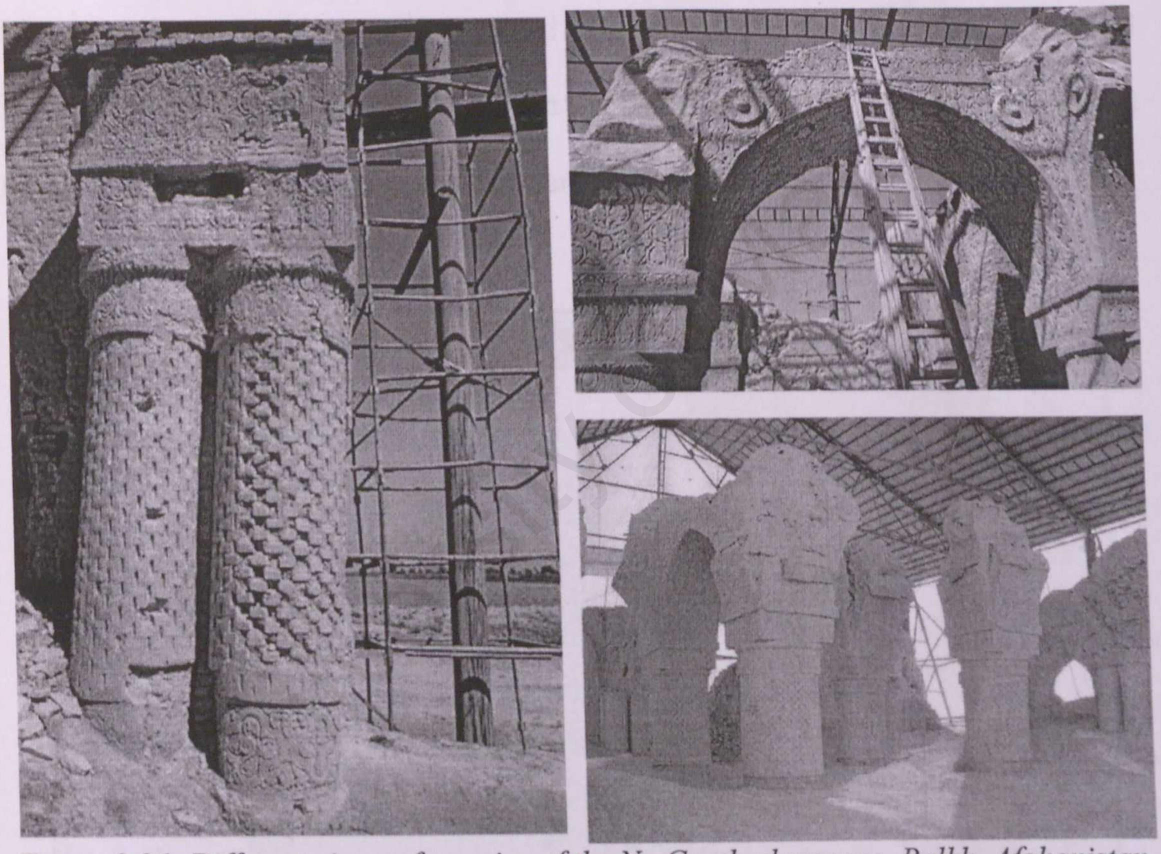


Figure 2.26: Different views of remains of the No Gumbad mosque, Balkh, Afghanistan (Sources: The Ministry of culture & Youth Affair in Afghanistan).

The mosque is aligned with *qibla* on the northeast-southwest axis and measures twenty-meters per side on the exterior. Inside, the prayer hall is divided into nine bays (three rows and three aisles) with triple archways. The arches rest on four thick columns at the center and pairs of columns (single at the corners) that are embedded into the Southeast, Southwest and Northwest walls (Golombek, and Wilber, 1988). The northeast wall opposite *qibla* opens to the exterior with a triple arcade carried on two additional columns. Three arched openings were pierced into each side wall, while the southwest wall (which contains the semi-domed *mihrab* niche) was left blind (Knobloch, 2002).

-Seljuks: By the 11th century, the first Turkish Islamic dynasty appeared as the Seljuks. In fact, they were Herdsmen descending from a Turkish tribe called Ghuz, who converted from old Shamanism (the Central Asian religion) to Islam. Since then they became devout Muslims striving and try to defeat unbelievers and declare it in all circumstances (Saud, 2003). Their rule quickly expanded to Persia, Azerbaijan and Mesopotamia entering Abbasid Baghdad in 1055 A.D., then Fatimid Syria, and Palestine. They defeated the Byzantines in the battles of Manzikert in 1071 A. D. and managed to hold and pacify Eastern and Central Asia Minor (Saud, 2003; fig. 2. 27).

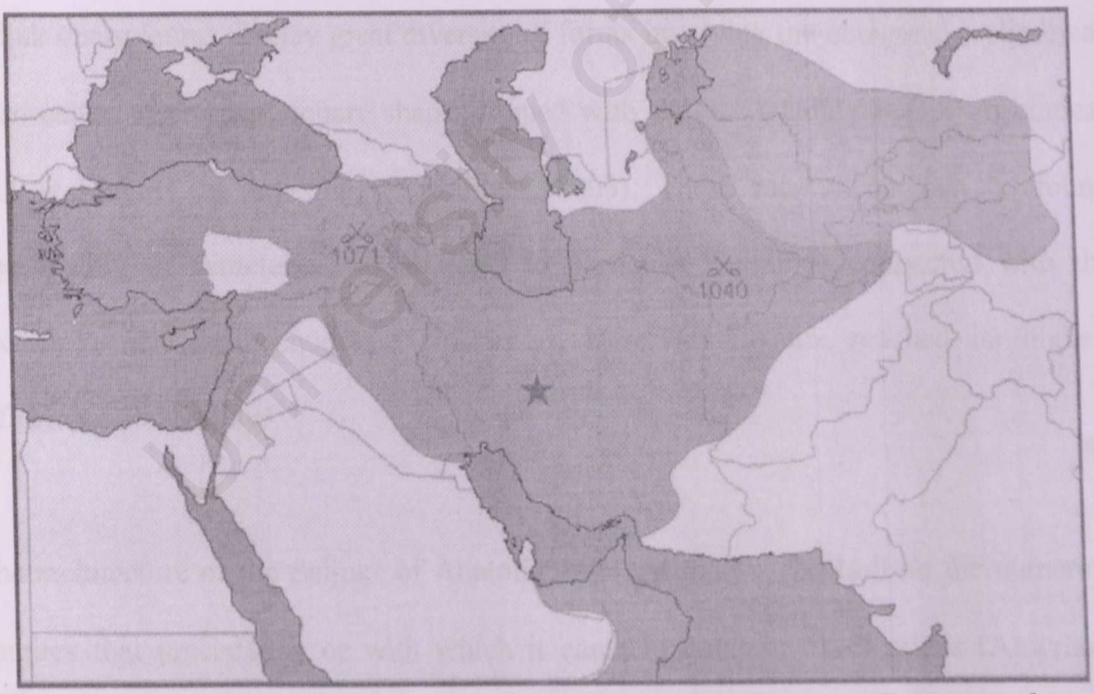


Figure 2.27: Map of the Seljuk Empire at its power before divorcing Eastern and Western territories.

The Seljuks rapidly adapted the general character of Islamic architecture in all their edifices due to the partly employment of Arab and Iranian architects and masons. In addition, the religious devotion of Seljuk leaders were identified more with the Islam rather than their geographical origin (Hillenbrand, 1976). Meanwhile, owing to the contact of the Seljuks with Persians and Central Asians, their cultural amalgamation likely enriched with a number of new features, techniques and building types (Hillenbrand, 1976).

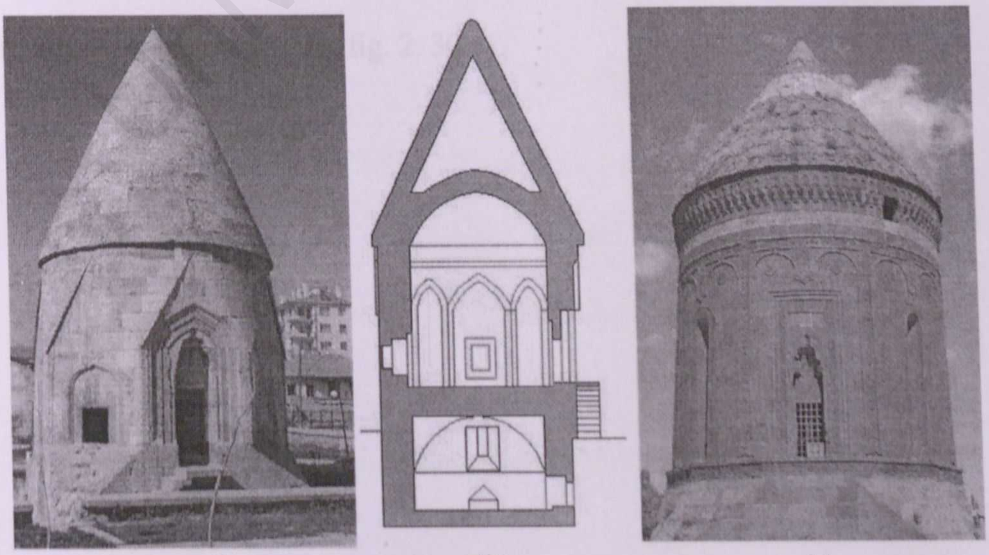
Architecturally, another building typology, which saw considerable development under Seljuk patronage, was funerary buildings or the mausoleum. This type of building evolved from early funerary monuments which were first erected to honor the Umayyad rulers in the 8th century (Saud, 2003). However, hosting the remains of important of both rulers and religion scholars took a new dimension under this dynasty. Their spread was particularly due to the diffusion of Sufism which trained widely practiced in Iran, Anatolia and Asia Minor (Saud, 2003).

Seljuk mausoleums display great diversity of forms involving the octagonal, cylindrical (also called tower) and square shapes topped with a dome (mainly Persia) or conical roof (especially in Anatolia) (Ayatollahi, 2003). These monuments can be found freestanding in cemeteries, or attached to particular buildings connected with the deceased such as mosques or *Madrassas*. Here, architecture reached its highest refinement and beauty.

The architecture of the Seljuks of Anatolia inherited many aspects from the numerous empires that preceded it or with which it came in contact: the Persians (Assyrians, Sassanians), the Greeks and Romans, the Armenians and the Byzantines. Although inspired by many design and construction elements, Seljuk architecture developed into its own distinct entity (Michell, 1978).

How the dome was involved in the Seljuk architecture is another distinctive feature. In this sense, The Suljuk's dome was supported by *squinches* in a peculiar triangular shape, known as "Turkish triangles". The inside of dome was often decorated with tiles or glazed bricks. They also developed the specific building form of the tomb tower, known as a "*kumbat*", or "*türbe*". Turbes were of two types: whether as a cylindrical tower with a low internal shell which sometimes covered on the outside with turquoise tiles; or polygonal (or octagonal) tower fitted onto a square base by using Turkish triangles which roofed with a conical turret (Saud, 2003). These comprised two stories lower floor often embraces a stone coffin and the upper floor serves as a main chamber with a *mihrab*. The entrance to the upper chamber was set fairly high on one side (Saud, 2003; fig 2.28 a, b).

In addition, Türbes are the translation of the former shamanistic tent of the Turkomans into stone tombs. An important number of them can be found in the city of Kayseri. No one ,who has seen the forest of gravestones and the eleven Seljuk türbes in the cemetery of Ahlat above Lake Van, can forget their poetry and mystical evocation (fig.2.28 c).



(a) (b) (c)

*Figure 2.28: Various types of Seljuk mausoleums; **a)** Melik Gazi tomb, 1200 A.D., Turkey; **b)** Vertical section of Melik Gazi tomb (Cross-section reporoducted by Maryam Ashkan from (Hillenbrand, 1994); **c)** Ulu Turbesi-Hasan Padish, Ahlat, Turkey.*

Apart from the funerary function of conical domes, various forms of pointed domes were also utilized for both mausoleum and congregational mosques which increasingly presented plain external appearances (fig.2. 29).

(a) (b) (c)

*Figure 2.29: **a)** Exterior view of Jamek mosque of Bersian, Iran (The Iranian Ministry of the Cultural Heritage (ICHO)); **b)** Interior view of under the internal shell and squinches (www.archnet.com); **c)** A hand sketch of cross-section of the dome chamber.*

One of the most important achievements of Seljuks is construction of the primary type of discontinuous double-shell domes in which the shells are completely disconnected. A couple of Persian tomb towers in Kharqan are considered as the earliest known discontinuous double-shell domes (6.45m span, 12.85m height) in the world (fig 2. 30; Mainstone, 2001). Both their internal and external shells have similar thicknesses and profiles. They were also composed without internal connections and interconnecting wooden struts (Mainstone, 2001; fig. 2. 30).

Figure 2.30: Twin towers of Kharagan, Iran.

Some of the valuable innovations in domical architectonic design that were undertaken during the Seljuk era are briefly listed as follows:

- To introduce the new concept of transition, '*Tromp-Patkana*' (fig. 2.29b);
- To expand continuous double-shell domes which were widely used in Iran;
- To create the conical discontinuous double-shell domes as an introduction to the development of double-shell domes.

-Ilkhanids and Timurids: The Ilkhanids were ancestors of the Genghis Khan (fig.2.31), who eventually converted to Islam and adopted Iranian culture. Since then, the material culture of Iran flourished again after the severe degeneration caused by several Mongol invasions. The main concept of Ilkhanid architecture is predominantly religious, charitable, and lesser extent to commercial functions (Wilber, 1955).

In this regard, majority of the remained monuments from this era have the religious nature and less are burial places. Perhaps, outstanding features of the Ilkhanid architecture relied on its readiness which proceeded common prior examples of the Seljuk era. The Iranian architecture under the Ilkhanids saw the widespread use of mosaic works with new bright-colored tiles and luster tiles for covering dadoes (Wilber, 1955).

In fact, architecture styles of the Ilkhanid period can be characterized as follows: huge monumental scale, sophisticated brick construction and portals which emphasized by using lavish ornaments, possibilities of decorative colorful glazed tile and the use of *muqarnas*-hoods. Also, they revived the function of the four-*iwan* plan, construction techniques, and funerary building types (e.g. tomb towers) topped with high pointed domes which the whole used by the former Seljuks masters (Hillenbrand, 1999a).

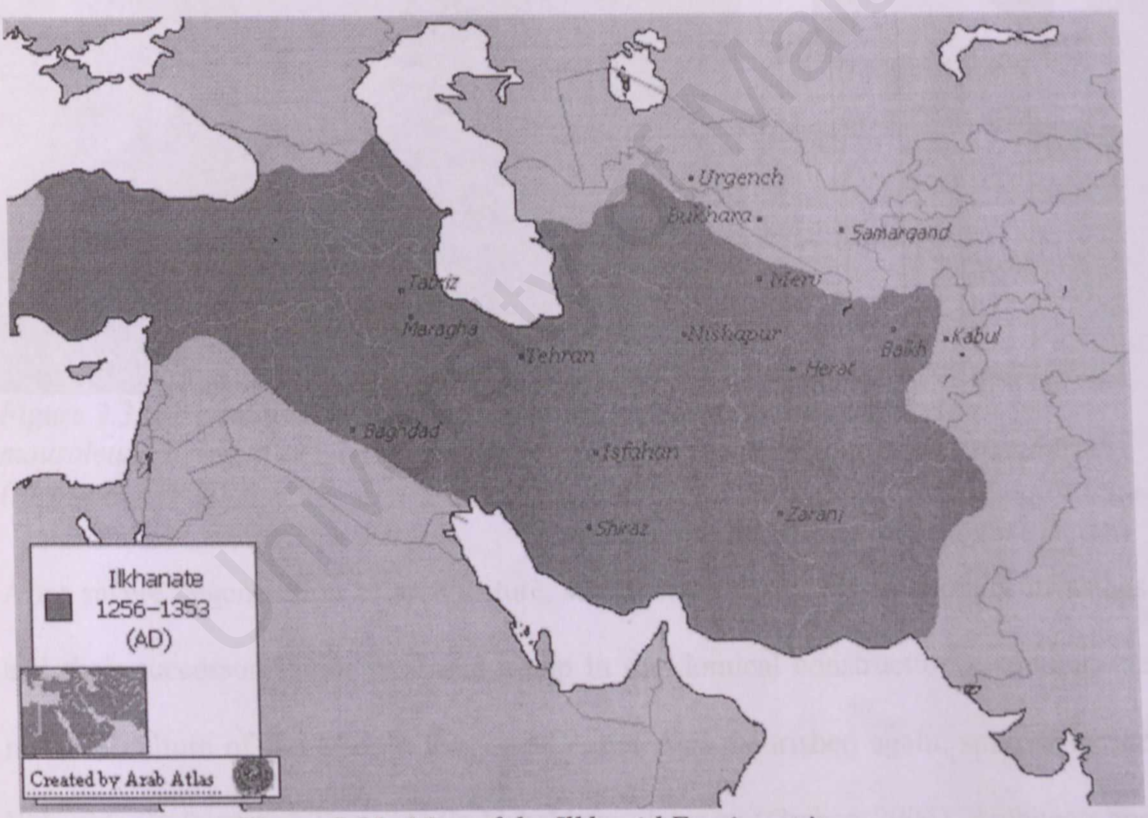


Figure 2.31: Map of the Ilkhanid Empire at its power.

Dome examples usually consist of continuous double-shells rested on huge structures. The use of *muqarnas* in the transition tier is one of the achievements of this period. The thin double-shelled dome was reinforced by arches between the shells (O'Kane, 1998). The dome over Sultan Bakht Aqa tomb (1351-52 A.D.) indicates major advance in the design of Persian dome configuration. It is the earliest known example of a double dome (7.5m span, 18m height) with developed composition of radial stiffeners and wooden struts in which the inner and outer shells have substantially different profiles (fig 2.32; O' Kane, 1998). This innovation for differentiating between the internal spaces and the external appearances of domes rapidly spread throughout various regions of the Middle East and Central Asia, and contributed to the creation of the united styles of the Timurid dome architecture later on.

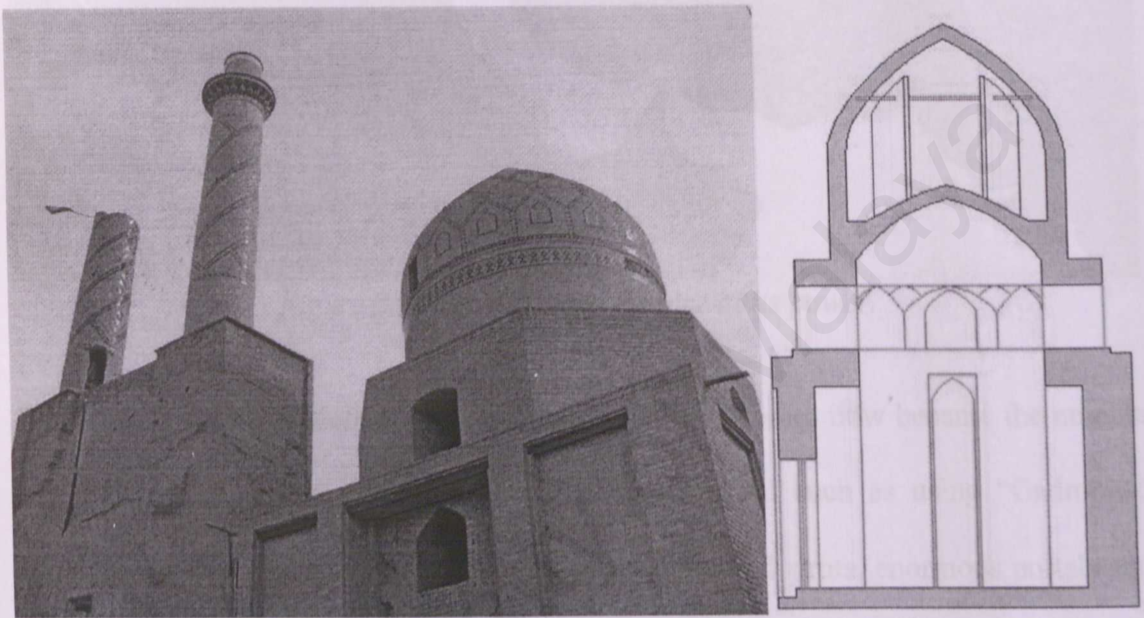


Figure 2.32: Discontinuous double-shell dome topped the Sultan Bakht Aqa mausoleum, Ilkhanid era, Isfahan, Cross-section reproduced by Maryam Ashkan from (Memarian 1988).

After severe degeneration of architecture, which was caused by the Mongol invasions and their successor Timur produced a gap in the domical construction evolution, the material culture of the Middle East and Central Asia flourished again, spurred by the Ilkhanids (in Iran) and Timurids (in Uzbekistan) later on (Grabar, 2006). Architects and artists from all the lands, from Asia Minor, Azerbaijan, the Caucasus, India, Iran, and elsewhere were forced to contribute to the construction of often colossal state buildings of both a sacred and secular nature (Michell, 1978; fig. 2.33).

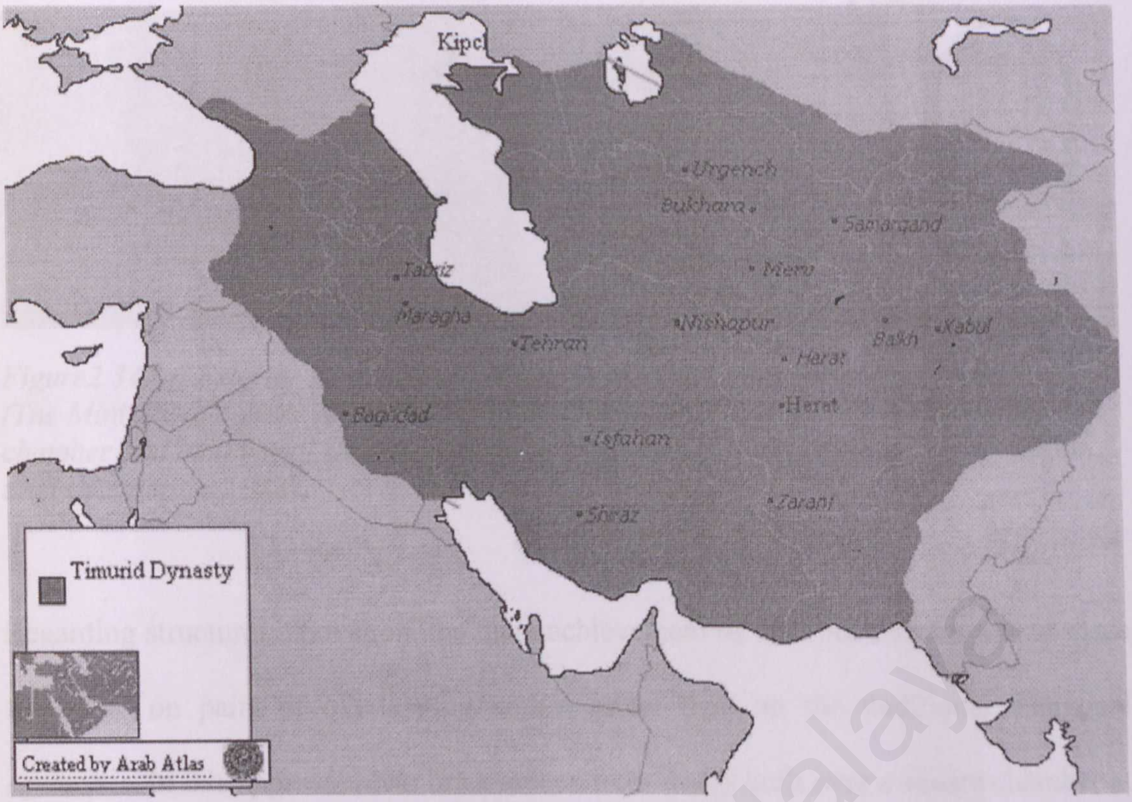


Figure 2.33: The Timurid Empire at its power.

The imposing composition of the monument enclosing domes now became the number one priority. Their structural items significantly evolved such as using "Gadrooned domes" (Yaghan, 2003) with developed setting of internal struts, enormous portals and elegance proportions that now became more slender (Pirniya, 1996).

In this regard, the most enduring sample of this primary trend is the triple-shell dome of Gawhar Shad mausoleum (1417- 38 A.D.) at Herat in Afghanistan which exposes the advanced level of structural knowledge, proportional developments, and the prevailing of local architecture by using fan-shaped *squinches* (Knobloch, 2002; Memarian, 1988; fig. 2. 34).

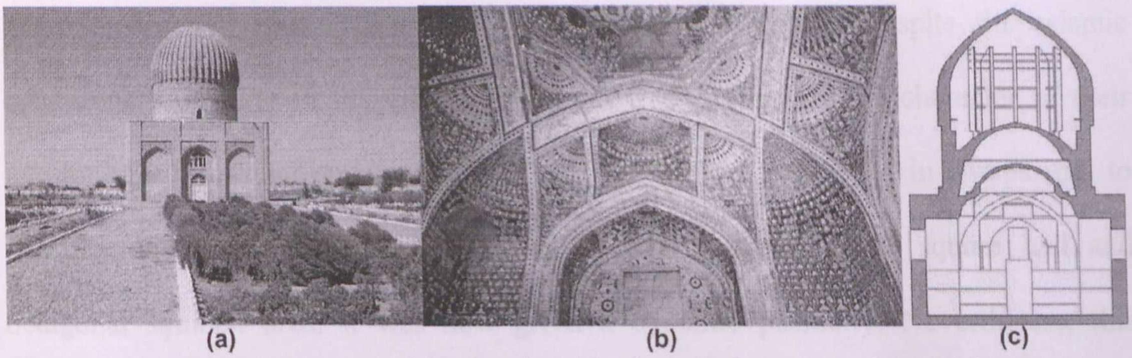


*Figure2.34: **a)** Exterior view of the Gawhar Shad mausoleum complex, Afghanistan (The Ministry of culture & Youth Affair in Afghanistan); **b)** Interior view of domical chamber and its internal shell (Source: www.archnet.com); **c)*** Mausoleum cross-section, after (Memarian, 1988).

Regarding structural innovation, the main achievement of the 15th century was to place the dome on pairs of overlapping arches rather than on the traditional octagonal *squinches*. In this approach, two brick arches were firstly built over a square chamber at an equal distance from the walls, and another two at right angles to them. In fact, they are overlapping at the top and formed a square base for the dome (Blunt, 1973; fig. 2. 35).

Figure2.35: Close views of the transition tier of the Tilla Kari mosque, Uzbekistan (Source: www.flickr.com/photos/83398740@N00/2458529403, upload by Simon White, 2008).

Then, the spaces between those vertices of the arches were filled in by shield-shaped spandrels and rhombus-like concave which were arranged geometrically between the main overlapping ribs of those standing arches. This type of spandrels was also used between the *squinches* of the octagonal parts of a dome.

This construction method not only was extremely successful despite the seismic conditions prevailing in the Central Asia, but it also changed the character of their interior space designs fundamentally (Blunt, 1973). Architecturally, in comparison to the previous static characteristics of the vertical progression of square hall and octagonal *squinch* area, it was now given a dynamic plasticity. Nevertheless, this technique had originated in the Middle East, probably in Armenia, where it had been known since the 12th century (Blunt, 1973).

Another important aspect of Timurid architecture made by collaboration of several celebrated mathematicians, that is, a variety of geometrical approaches which had widely used for designing domes (Hogendijk and Sabra, 2003).

***-In the 15th-17th centuries and after*:** Consequently, the dome architectures were rapidly incorporated and altered into local styles after the Timurids epoch by appearing three specific local dynasties (Hillenbrand 1999b) including: the Safavids in Iran (1501-1732 A.D.), the Shaybanids in the Central Asia (1503- ca. 1800 A.D.), and the Mongols in India (1525-1858 A.D. out of scope of this research)

The emphasis on the greatness of buildings, which reached its high level of evelopment in the Timurid era (Gangler, 2004), continued to be a principle in the Saffavid Empire (16th -17th Century) including Persia and nearby areas. The most significant accomplishment of this era embraced distinct bulbous domes (2. 36a) which are considered as the last generation of Persian domes. They exerted great influence on architectural styles of Islamic domes, especially in the late Mughal period in India (Ashkan and Yahaya, 2009; 2. 36b).

On the other hand, the dominant features of the Saffavid domes are general use of lighter structures (by reducing the thicknesses of shells and walls), lots of colored glazed tiles (e.g., yellow, green, blue, and gold), and complex nets of vegetation (Ashkan and Yahaya, 2009).

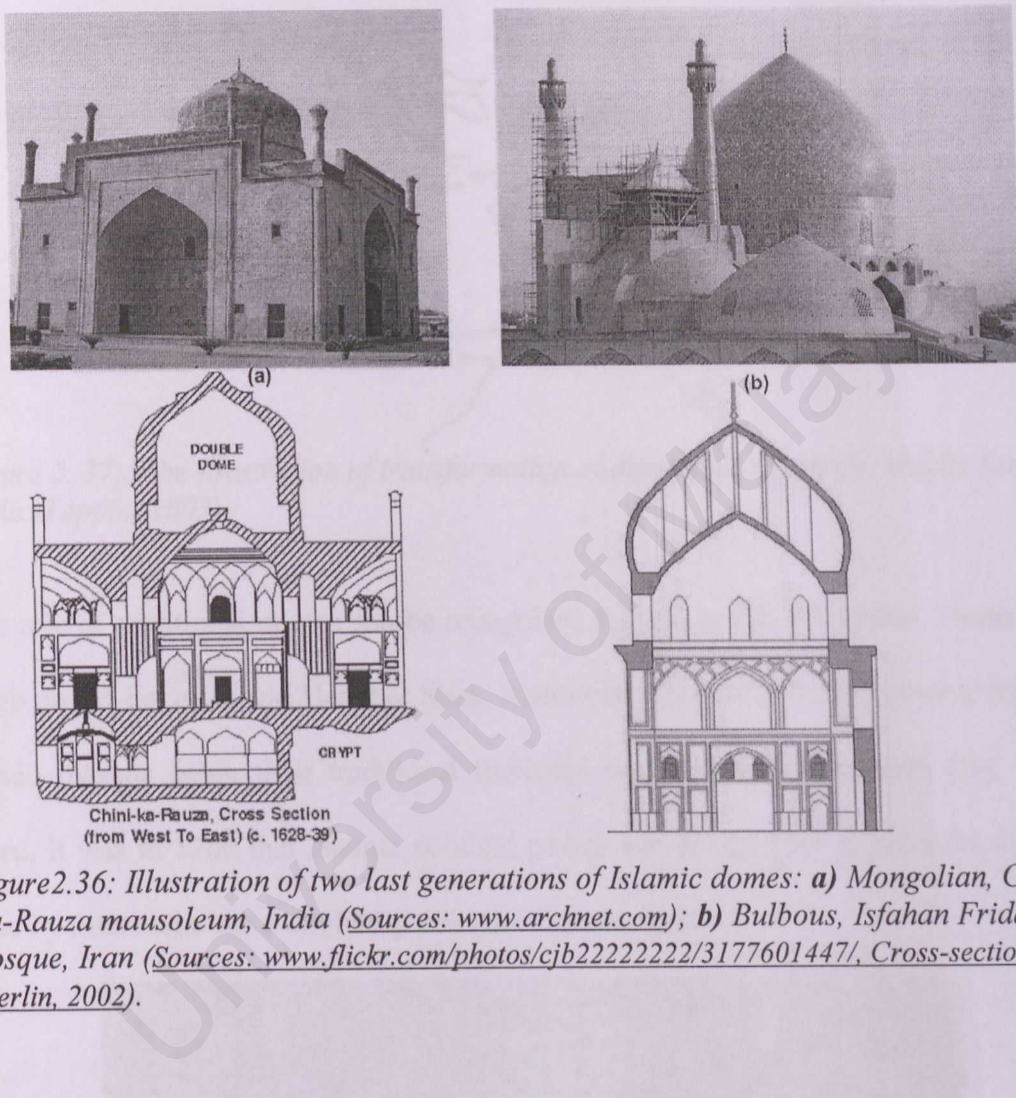


*Figure2.36: Illustration of two last generations of Islamic domes: **a)** Mongolian, Chini Ka-Rauza mausoleum, India (Sources: www.archnet.com); **b)** Bulbous, Isfahan Friday mosque, Iran (Sources: www.flickr.com/photos/cjb22222222/3177601447/, Cross-section after Stierlin, 2002).*

In fact, these major changes probably originated in 15th century experiments with the concept of using intersecting arches to support a dome with a diameter smaller than the width of the square below. The chamber was also modified, with a deep recess added to each side to produce a cruciform plan. The result was a much more fluid space than had been possible with the rigid tripartite division of lower square, zone of transition, and dome (O'Kane, 1998).

i. *Indian Domes During Delhi Sultanate and Mughal Rulers*

The domes of India are a unique synthesis of Islamic and Hindu influences. Many of the key buildings in the evolution and development of domes are in Delhi along with the monuments in Agra and Bijapur (fig. 2. 37).

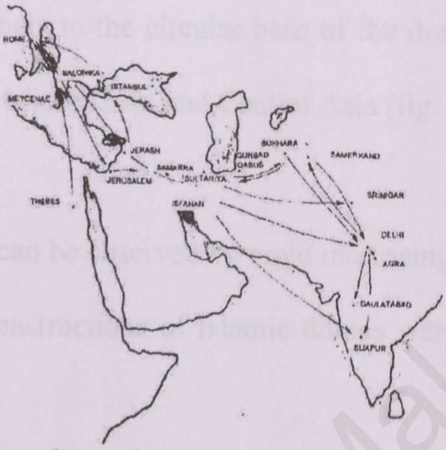
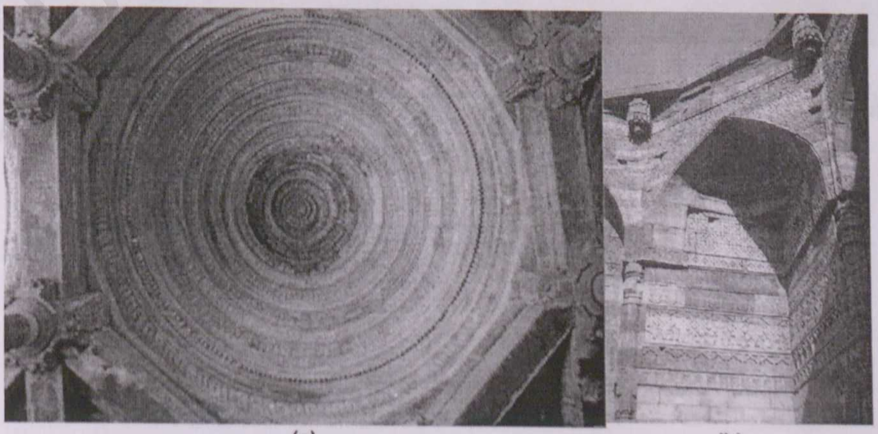


Figure 2. 37: The Illustration of transformation of dome styles from the Middle East to India (Tappin, 2003).

The role of traditional domes can be recognized by having the Taj Mahal, Humayun's tomb on the list of World Heritage Sites. Historically, the early buildings were built by Hindu masons using their traditional trabeated methods of construction (fig. 2.38). Then, it was in 1206 that Islamic political power was established in India for the first time by rulers who were originally from the Central Asia.

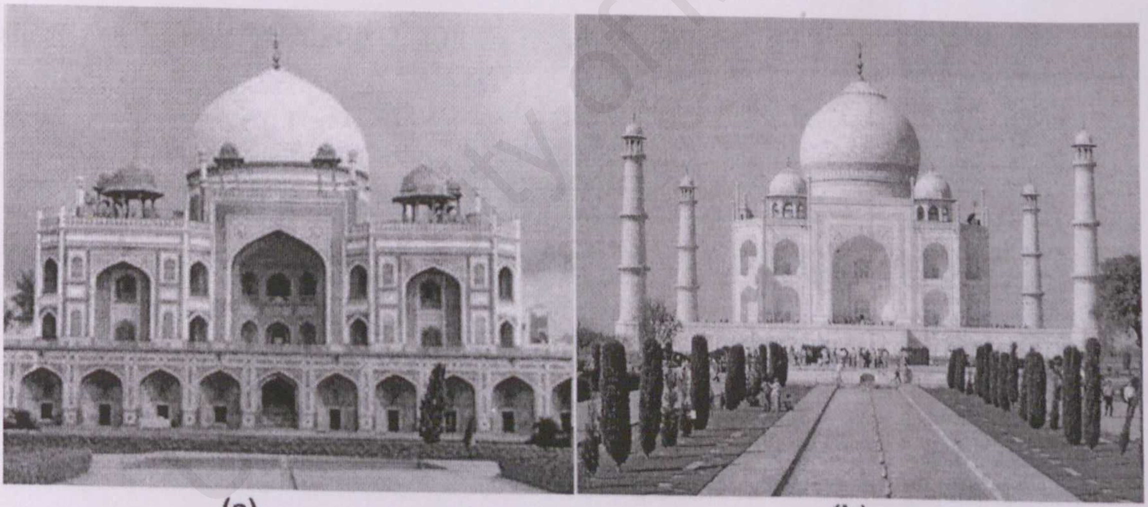


(a) (b)

*Figure 2. 38: Illustration of two primary types of Indian domes: **a)** Ajmer mosque, 1200/1206 A.D., Ajmer; **b)** Qutb Complex, Iltutmish Tomb 1220/1236 A.D., Delhi. (Source: www. Archnet.org)*

After several constructions of one shell corbelled domes, eventually, double-shell domes had significant after in Indian Islamic architecture and the regions under its influence. Though, the gap of reduction in masonry skills occurred due to a loss of understanding of how to structure buildings by stone. It is interesting to highlight that the knowledge of how to build true arches and domes, and techniques of transition from a square or octagonal chambers to the circular base of the dome basically linked with technical experiments of the Middle East and Central Asia (fig. 2.39).

Nevertheless, this influence can be observed by rapid increasing of numbers of domes in the late Islamic era when constructions of Islamic domes were inclined in the Middle East and Central Asia.



(a) (b)

Figure 2.39: ***a)*** *Mughal Emperor Humayun's tomb, 1562 A.D., Delhi;* ***b)*** *Taj Mahal mausoleum, 1632/53 A.D., Agra.*

2.5 The Eastern Domes: Morphology and Typologies[4]

The dome can be considered as a structural consonance and a hierarchy of ordered parts, that is, the relationship between internal space and structural mass or positive-negative spaces. The previous historical studies of the Eastern domes make the task easier to deduce a basic list of recurring generic forms for understanding principles of their architectural configurations (Ashkan and Yahaya, 2006).

Additionally, it is noted that the visual language to be presented is only a "set of tools", may also call "*vocabulary*" (Ardalan, 1980) related to a mode of architectural expression. The dome, whether the Eastern or the Western one, chiefly consists of the four common components: Supporting system, Transition tier, Drum and Shell(s) (Ashkan and Yahaya, 2006; fig. 2. 40).

Refer to the Chapter one- pages 14 and 15 for the extensive elaborations of both morphology and typologies.

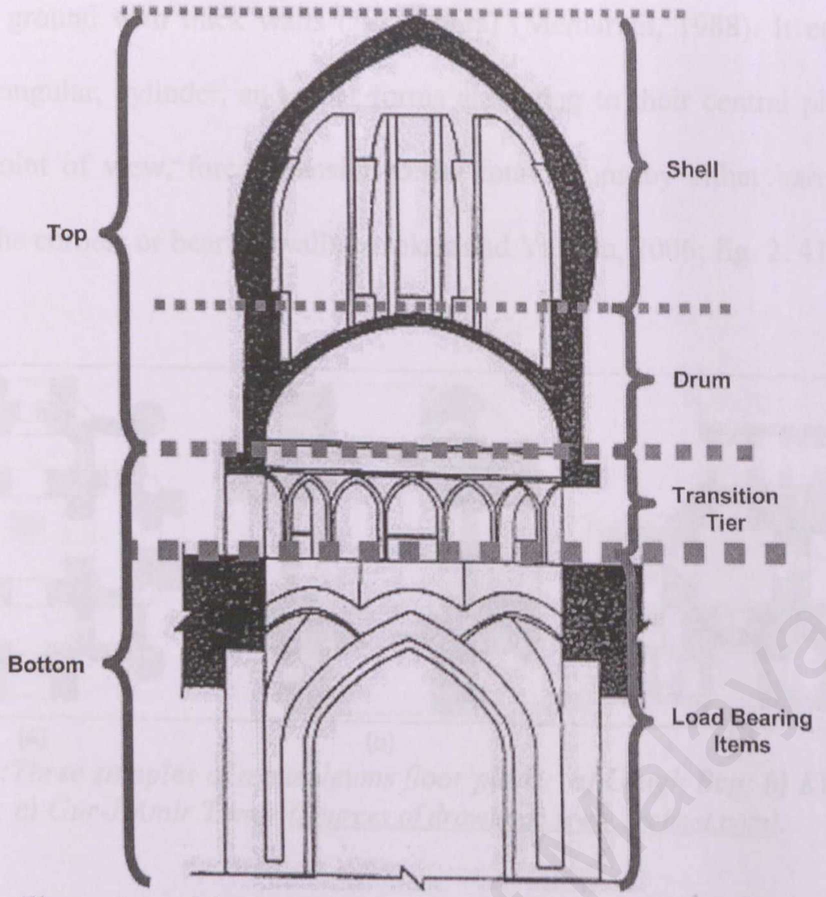


Figure2.40: Illustration of the four common components of Eastern domes (cross-section after Memarian, 1988).

Architecturally, the dome can conceptually be divided into two main parts: top and bottom, where each part involves its own elements and sub-types forms. The top of dome consists of internal shell, external shell, and drum. The bottom of dome includes transition tier and supporting system which often embraces two common compositions: load bearing walls and barrel vaults. The dome elements, sometimes, are composed together proportionally and mathematically such as, Taj-al-Mulk dome of Jamek mosque which is the most beautiful structure and ultimate sample of the Seljuk architecture in Persia.

2.5.1. Bottom of Dome: Supporting System

A definite concern for load-bearing items arrangement in space is that the structural system must fulfill the requirements of the building's statics by transferring the vertical load to the ground with thick walls (1-2 meters) (Memarian, 1988). It embraces the square, rectangular, cylinder, and taper forms according to their central plans. On the structural point of view, forces transfer to the foundations by either barrel vaults as buttress at the corners or bearing walls (Ashkan and Yahaya, 2006; fig. 2. 41).

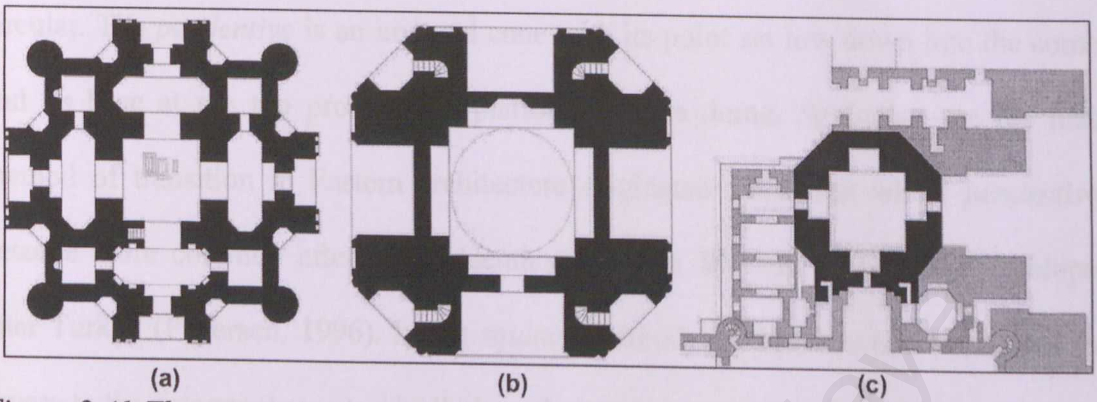


*Figure 2.41:Three samples of mausoleums floor plans: **a)** Olugh Beg; **b)** Khaja Abu Nasr Parsa; **c)** Gur-I Amir Timur (Sources of drawings: www.archnet.com).*

2.5.2. Bottom of Dome: Transition Tier

The transition tier is the structural feature designed to take the horizontal thrust of the top of the dome; hence it must be able to transfer this thrust to the load supporting items at the lower course of the building (Blair, 1983).

But, one of the main problems of traditional dome construction was the transition from a square space or area into a circular base of dome. This led to various construction techniques. In the primary step, the square shape of plan converted to octagonal area from, which facilitated its converting to a circular disc, though there is still the problem of converting from octagon to square (Dome, 2007). In this sense, two main methods were traditionally adopted: these are *pendentives* (fig. 2. 42a) and the *squinches* (fig. 2.42b). Essences of both, however, derive from Eastern countries: Turkey and Persia. Then, when the Romans conquered the Middle East, the dome was incorporated into

Roman architecture and under the Byzantines. Soon later, it became the main method of roofing Western monumental buildings (Grabar, 2006).

The *squinch* is a mini-arch which is used to bridge a diagonal corner area whilst a dome needs the four mini-arches or arching for primary conversion from the square to the circular. The *pendentive* is an inverted cone with its point set low down into the corner and its base at the top providing a platform for the dome. *Squinches* are the main method of transition in Eastern architecture originated from Iran whilst *pendentives* became more common after the sixteenth century in Western architecture developed after Turkey (Peyersen, 1996). In the *squinch* method, the builders had exchanged the square to the octagonal area gradually by using projected mini-arches.

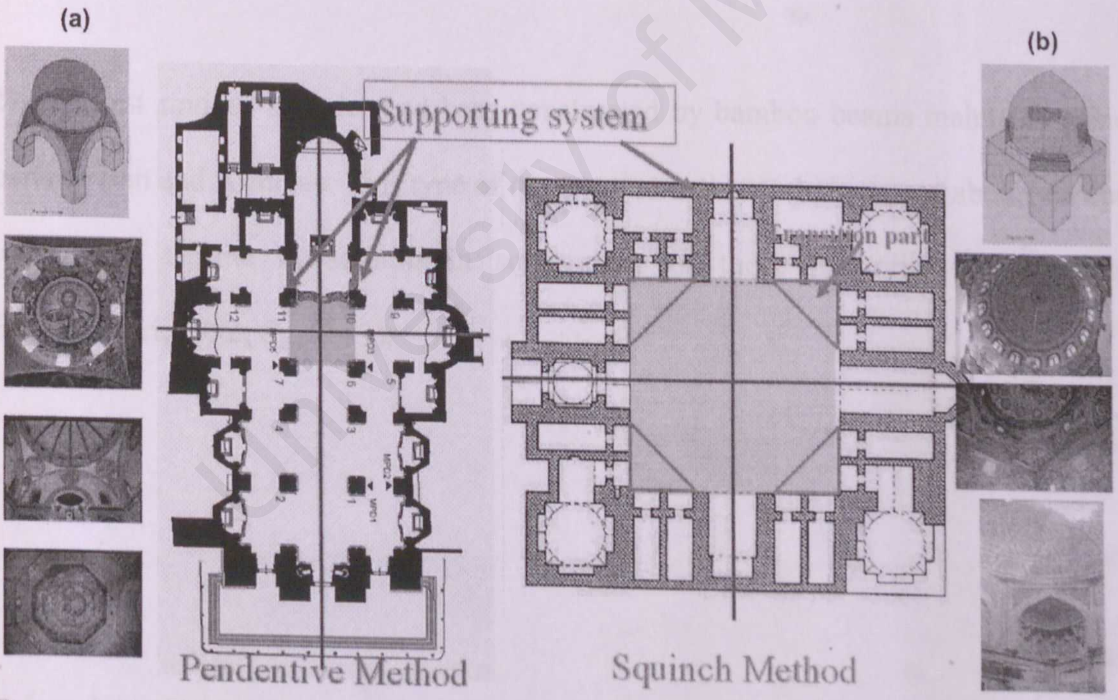


*Figure 2.42: Illustration of two methods of transition tier construction; **a)** Pendentives in Western style; **b)** Squinches in Eastern style.*

In fact, in every domical form, the treatment of shell as crowning element is more or less the same; the most original feature of these structures lies in the levels of transition elements and their connections (Turan, 1993).

Overall speaking, this component often consists of two stories of interesting trilobed arches which protrude over the lower row. According to the main meanings of *squinches*, these mini-arches were used to bridge diagonally the four transition corners for easily converting from square to the circular base of the shell. Here, distinct geometrical procedures allowed an infinite numbers of compositional variations on those mini arches to be developed and also amalgamated the small fragments of these components. Architecturally, these crossing mini-arches yielded a visual link between the body of dome and crowning shell. Structurally, the role of these elements is to partially transfer the localized forces in such a way that both vertical and horizontal forces are concentrated on small regions of transition tier.

i. *Evolution of the Squinch Transition Tier*

The earliest *squinch* samples had been constructed by bamboo beams mainly in some parts of Iran and Armenia. This type of dome construction technique was abolished due to existing termite infestations in some parts of those territories (Pirniya and Bozorgmehri, 1992; fig. 2. 43).

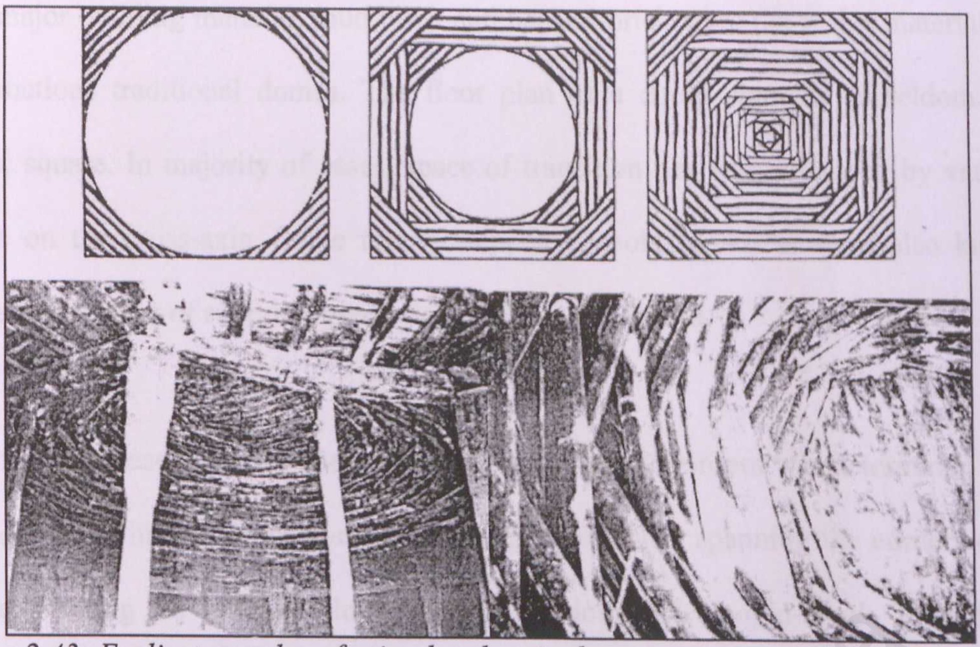


Figure 2.43: Earliest samples of using bamboo in dome construction, Iran (Pirniya and Bozorgmehri, 1992).

Historically, it is an example of a transformation center of pre-Islamic building forms belonging to the Sassanian period which is exemplified by the great temple of the *Ardeshir* palace (Ayatollahi, 2003; fig. 2. 44a).

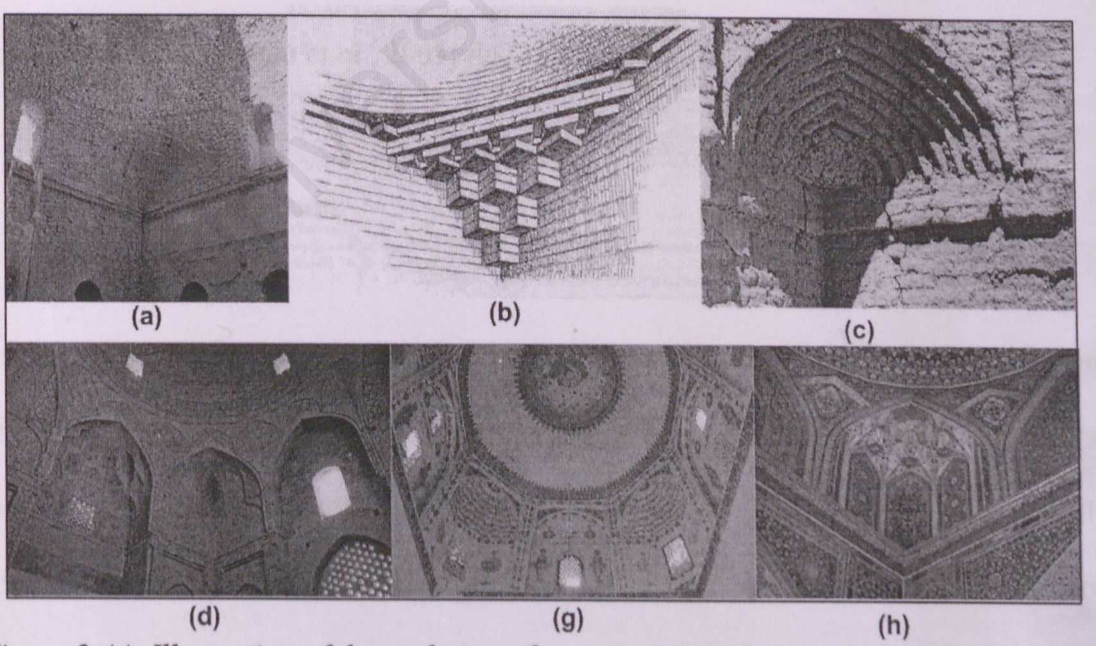


Figure 2.44: Illustration of the evolution of transition tier concepts since the pre-Islamic until the late-Islamic era. (Sources: ***a)*** *The Iranian Ministry of the Cultural Heritage (ICHO);* ***b, c)*** *Necipoglu et al., 2005;* ***d, g)*** *www.archnet.com;* ***h)*** *www.flickr.com/photos/83398740@N00/2458529403, upload by Simon White, 2008).*

As a major building material, mud-brick and backed-brick were the major materials for constructions traditional domes. The floor plan of a dome chamber is seldom as a simple square. In majority of cases, space of transition tier was expanded by vaulted-niches on the cross-axis. Some times, Stepped console spandrels were also known, consisting of rows of superimposed brick brackets (fig.2. 44b, c).

But the round base of dome where it met the top of a square room was determined by its *squinch* plan which was achieved by erecting mini-arches spanning the corners of the square, forming the octagonal lower part of the dome (Necipoglu *et al*., 2005; fig. 2. 44d, g).

By the 11th century, these mini-arches were converted to the basis of the stalactite structures (*muqarnas*) and later on became very widespread in the late Islamic era. The whole arches as well as the cross-section of domes were generally pointed. Here, a geometrical procedure allowed an infinite number of variations on the pointed arch to be developed (Necipoglu *et al.*, 2005; fig. 2.44h).

2.5.3 Dome's Top: Drum

An essential part in the dome construction and connection between the top and bottom of the dome is its drum, that is, the cylindrical part of the dome on which the shell(s) rests. Many of these drums are many-sided instead of being circular in plan, externally (Poole and Giambo, 2007). The carrying-up of the walls vertically is a good constructional expedient as it should bear weights of the haunches of the dome and helps to neutralize their thrusts.

2.5.4 Dome's Top: Shell(s)

Shell of the dome evidences principles of centrality and symmetry; these are seen as the main causes for distinguishing between varieties of geometric shapes. In fact, it is only the dome's architectural form which was used synonymously in several climes.

In the double-shell domes shells may identify as the internal and external shells. Both thicknesses of shells proportionally reduced from their bases to the top at either 25' or 30' angles, for the purpose of reducing the overall weight of shells structurally. The internal shell has the simple forms such as pointed, semi-circular, semi-elliptical, and saucer (Figure 15), though the external shell is the final crowning element which is likely to appear alike amongst the studied samples.

Alongside these, the key in understanding of diversities in the external shell forms mainly dealt with studying of their geometrical concepts, namely, "*profile*". This profile can be obtained by diminishing the thickness of cross-section of external shell. It consists of numbers of whether two or four small arcs. Depending on the position of the center points, the shapes of these profiles are considerably different. Structurally, proper geometrical forms utterly reduced tensions throughout the external shell (Frashad, 1977; Hejazi, 1997).

The number of shell(s) can be varied from the one shell to the three shells based on the style and period (Memarian, 1988; Hejazi, 1997; fig. 2. 45). In this sense, morphologically, in the construction of the Eastern domes, these shells can be put together in three different ways (fig 2.45). These include one shell (the earliest type of the eastern domes: (OS-Type 1 and OS-Type 2), two shells and three shells (Hejazi, 1997). However, few samples of these triple shells that emerged in comparison to large numbers of the other sorts can thus verify its origin from the double-shell domes (Grangler, 2004).

Regarding the double-shell types, two subdivision groups have been defined based on how these two shells are composed together. They are the continuous and the discontinuous groups.

In this type of domes, external shell is subject to the exterior appearance and stylistic matter of dome and may consider as the only common component amongst variety of domes; whereas, its internal shell mainly encompasses for both structural characteristics and architectural design purposes in such a way that have often exhibited in different shape and geometry.

In the continuous double-shell domes, sometimes, there exists no considerable distance between the shells (CD-Type 1), or they are connected by brick connectors (CD-Type 2), but very often the distance between these shells are small (CD-Type 3) (Hejazi, 1997). It could thus be said that the continuous two shells domes are called 'evolving' from the one shell domes to the two shells domes in the Islamic dome architecture development. The constructions of the one shell dome were continued up to the late Islamic era (Stierlin, 2002).

In the discontinuous double-shell domes, there are considerable distances between the two shells. The discontinuity may start either from the base (DD-Type 3) or from the top of the drum (DD-Type 1 and 2) (Hejazi 1997). This is considered higher than the other types of the Islamic domical typologies (DD-Type 2; TS-Type 1).

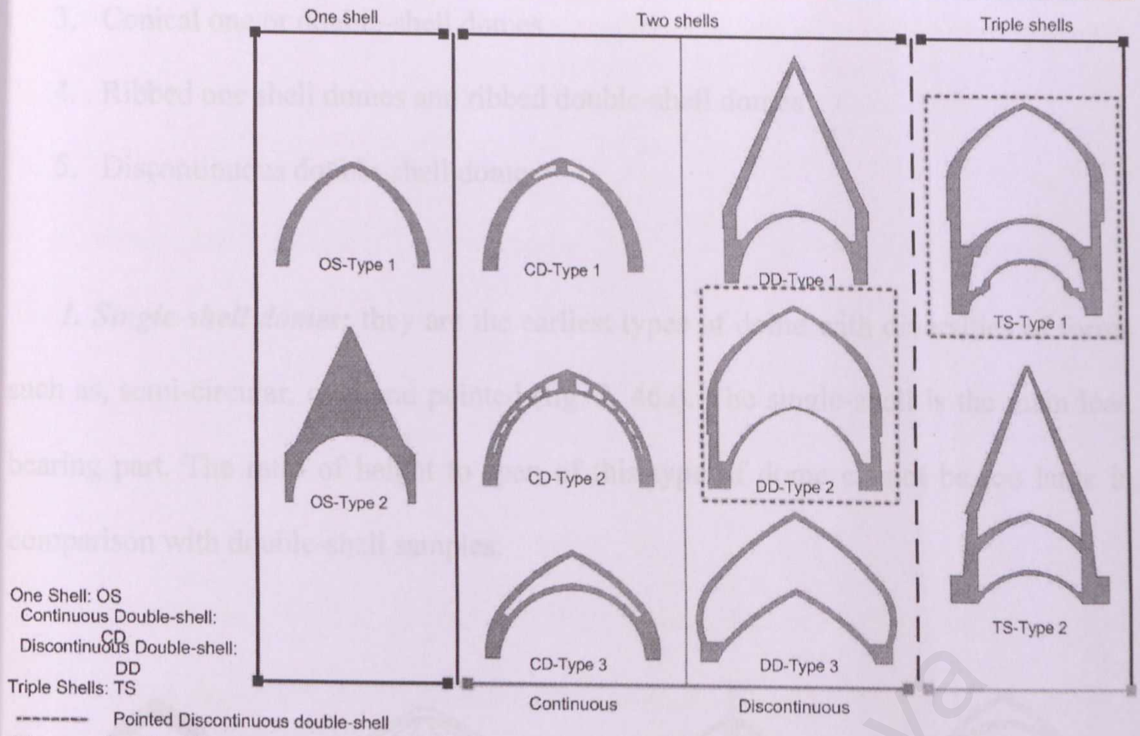


Figure 2.45: Illustration of the Islamic dome typologies according to their shell(s) compositions. Reproduced by authors from (Hejazi, 1997).

Nevertheless, the assemblies of those generic forms are fully conformed with the specific geometric scheme that control their organization as a whole. Although, several studies have been chiefly carried out in the recognition of the generic vocabularies, but the frequency of each component in the different parts of Middle East have not been fully identified. The works of Gh. Memarian (1987), Gh. Memarian and M. K. Pirniya (2003), M. K. Pirniya and Z. Bozorgmehri (1992), T. H. Poole and G. Giambo (2007) may be highlighted to illustrate the general features and historical considerations about general features and typologies of the Eastern domes.

In addition, Memarian (1988) also highlighted the specific hierarchy of domes according to their shell compositions, as follows, however, he do not clearly explain the typical morphological features of these domes in Eastern lands:

1. One shell domes
2. Continuous double-shell domes

3. Conical one or double-shell domes
4. Ribbed one shell domes and ribbed double-shell domes
5. Discontinuous double-shell domes

***1. Single-shell domes*:** they are the earliest types of dome with diversities of forms such as, semi-circular, oval and pointed (fig. 2. 46a). The single-shell is the main load bearing part. The ratio of height to span of this type of dome cannot be too large in comparison with double-shell samples.

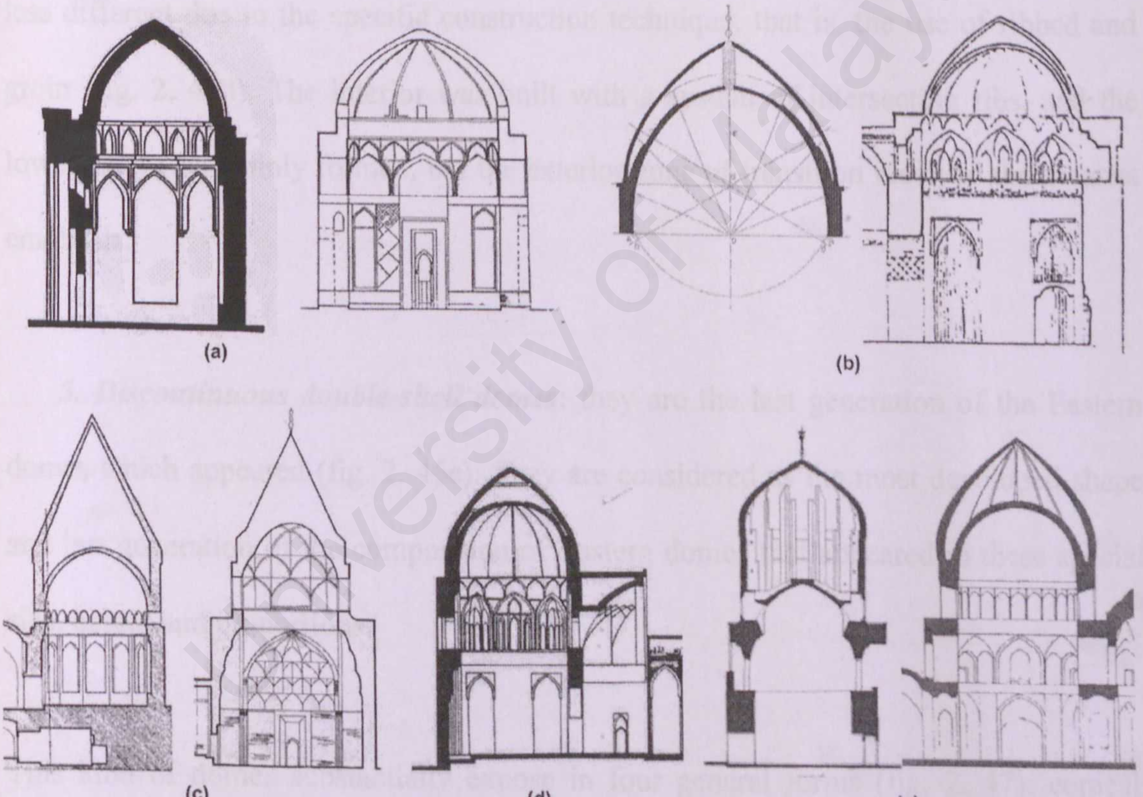


Figure2.46: Categories of dome typologies according to their shell compositions: ***a)*** *Single-shell dome;* ***b)*** *Continuous double-shell domes;* ***c)*** *Conical one shell and double-shell domes;* ***d)*** *Ribbed one shell domes and ribbed double-shell domes;* ***e)*** *Discontinuous double-shell domes (Sources: Memarian, 1988; Pirniya and Bozorgmehri, 1992; Hejazi, 1997).*

2. Continuous double-shell domes: in this sort of dome, the distance between the two shells is small and shells are connected at an angle of 22.5' by brick connectors (fig. 2. 46b). Then, the discontinuity is started. These kinds of domes are considered as the middle step of the Eastern domical evolution from the one skin to the discontinuous double-shell domes. Internal and external shell forms basically are different.

***3. Conical one or double- shell domes*:** The external shell shape is commonly a conic shape whilst the internal shell is almost always a reverse parabolic shape (fig. 2. 46c). This type of dome was a popular style in the Seljuk era and which has never been traced again. Sometimes, there is a considerable distance between the two shells.

***4. Ribbed one shell domes and ribbed double-shell domes*:** This group is more or less different due to the specific construction technique, that is, the use of ribbed and groin (fig. 2. 46d). The interior was built with a system of intersecting ribs, and the lower shell was plainly formed, but the exterior zone of transition received the greatest emphasis.

***5. Discontinuous double-shell domes*:** they are the last generation of the Eastern domes which appeared (fig. 2. 46e). They are considered as the most developed shape and last generation of the composition of Eastern domes that appeared in these special size, height and proportions.

This kind of domes substantially expose in four general forms (fig. 2. 47): conical, bulbous, Mongolian, and pointed. The continuous double-shell domes are considered as primary samples of evolution from one shell to two shells domes.

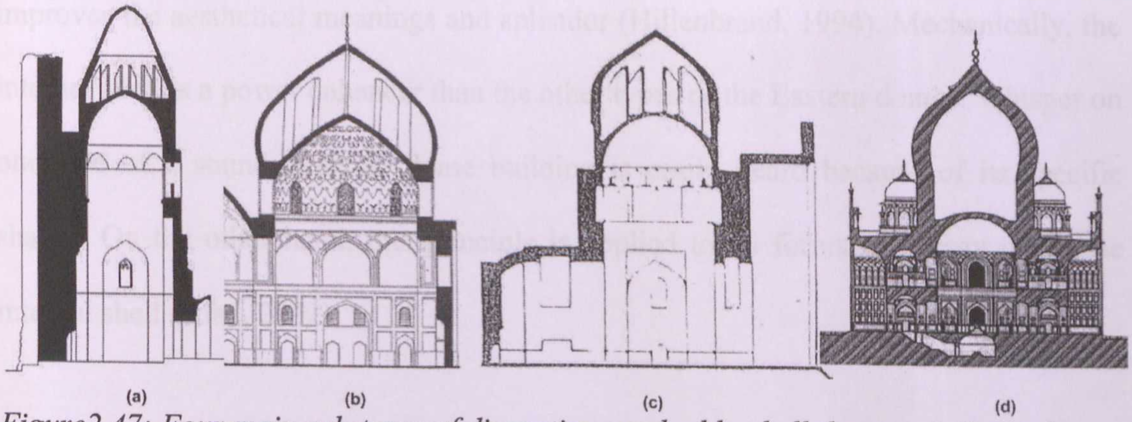


Figure2.47: Four main sub-types of discontinuous double-shell domes: ***a)*** *Conical, Jahangir mausoleum, Uzbekistan (Memarian, 1988);* ***b)*** *Bulbous, Shah mosque (Masjid-e Imam), Iran, (Stierlin, 2002);* ***c)*** *Pointed, Kalyan mosque, Uzbekistan, (Memarian, 1988);* ***d)****Mongolian, Taj Mahal mausoleum, India,* *(www. archnet.org/courses/MughalIndia/HistoricIndia.html).*

2.6 Historical Outline of the Origin and Development of the Pointed Discontinuous Double-shell Domes in Historical Architecture

As mentioned before, spiritual meanings were an important cause of the dome development in the late Islamic architecture. Because of this, the pointed discontinuous double-shell domes, as the primary result of this idea, rise up more vertically for the purposes of emphasizing on the request symbolic meanings.

Their specific configuration had the chief advantages of divorcing the weathering surface from the inner shell and thereby substantially giving improved weather protection (Mainstone, 2001). Structurally, the weight for a given overall breath of construction is reduced by using the light shells. Its construction method also was extremely successful despite the seismic conditions in the Middle East and Central Asia (Hejazi, 2003).

Architecturally, it permitted an increase in the external size and height of the dome to make it more imposing without necessarily increasing the height internally, which improves the aesthetical meanings and splendor (Hillenbrand, 1994). Mechanically, the internal shell is a power enhancer than the other types of the Eastern domes. Whisper on one side of a sound-reflected dome building is easily heard because of its specific shapes. On the other hand, this principle is applied to all forms of energy under the internal shell (Irfan, 2002).

Generally speaking, the pointed discontinuous double-shell domes are, in retrospect, resulted from fairly continuous development of the practice of the dome generous proportions to reach the meaning of 'centrality' in Islamic architecture (Michell, 1978). Historically, in the cases of the primary pointed shells, the earliest known discontinuous double-shell domes crown a pair of the eleventh century Iranian tomb towers (fig. 2. 48). Both appear to have had the internal and external brick shells of similar thickness and profiles. These shells were completely independent of one another, apart from a few interconnecting timber struts. They may demonstrate primary attempts in designing a solution to make the conflict between the external appearance of the domes and its aesthetic interior space (Mainstone, 2001).

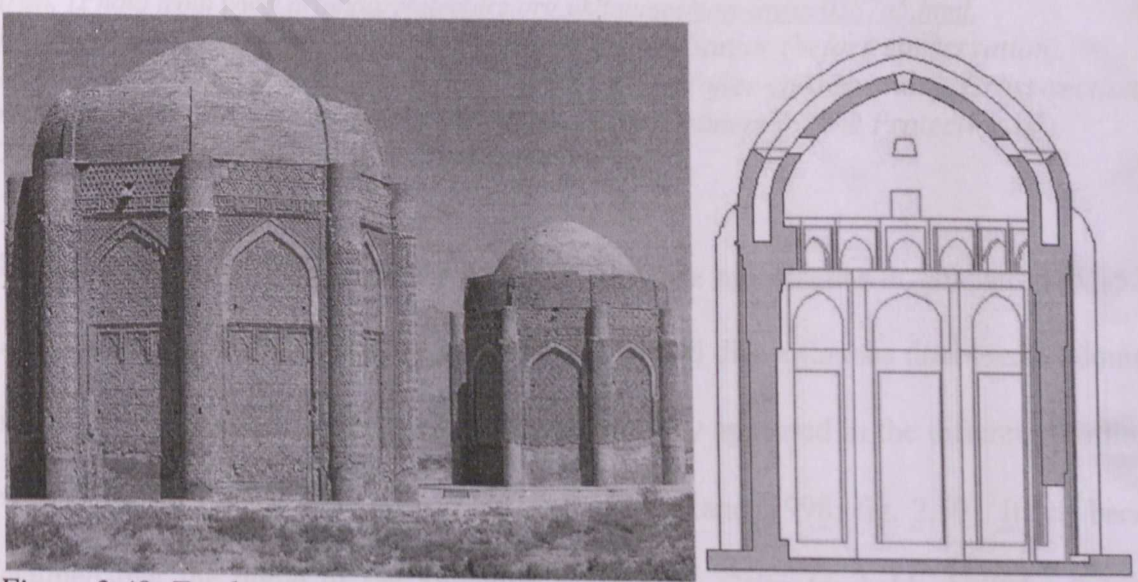


Figure 2.48: Tomb towers with discontinuous double-shell domes, Kharraqan, Iran. Cross-section reproduced by Maryam Ashkan from (The Iranian Ministry of the Cultural Heritage (ICHO)).

Another typical typology of monuments, which underwent considerable development under the Seljuk patronage and was exceedingly used by Mughals later on, is those mausoleums with their developed architectonic configurations, regionally located in the greater Khorasan[5] (figure2. 49). They consist of the two stories cube shape topped with the huge unlike double-shell domes (Saud, 2003). Study of the damaged external shells of these pointed samples may demonstrate the lack of determining the structural stability and knowledge of proportional design. In fact, there remained no a completed standing of the pointed discontinuous double-shell before involving the Islamic mathematic and geometric scientists in architectural, structural and geometrical designs of these kind of domes (Memarian, 1988).

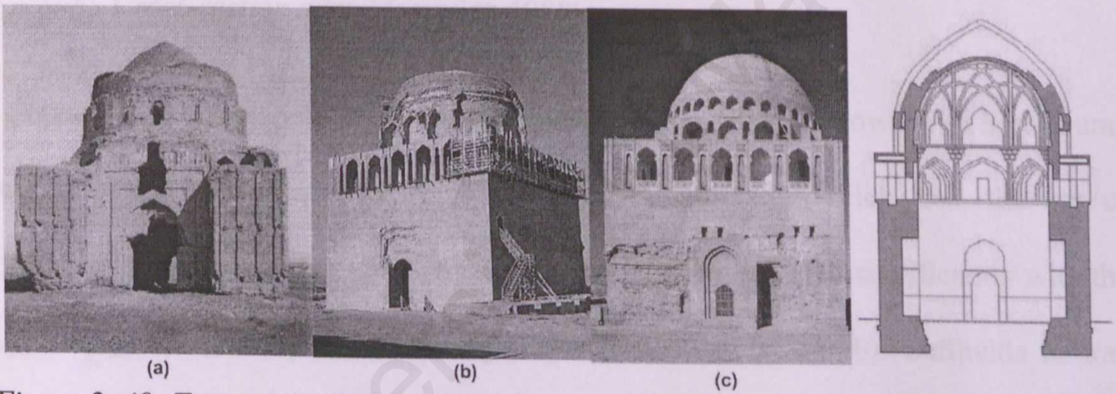


Figure 2. 49: Two stories Seljuks mausoleums; ***a)*** *Anonymous mausoleum, Khorasan, Iran, (Photo from www.artandarchitecture.org.uk/images/conway/ac0587a5.html, Photographer: Robert Byron);* ***b)*** *Mausoleum of Sultan Sanjar (before conservation), Merv, Turkmenistan;* ***c)*** *Mausoleum of Sultan Sanjar (after conservation). Cross-section reproduced by Maryam Ashkan from (National Department for the Protection of Turkmenistan Historical and Cultural monuments).*

In this regard, the dome over the Sultan Bakht Aqa mausoleum in Isfahan (1351-52 A.D.) is the earliest known example of the completed discontinuous double-shell dome in which the inner and outer shells have substantially appeared in the different profiles with radial stiffeners, as shown in figure 2.46 (O'Kane, 1998; fig. 2.50). It has been claimed that the dome of the Sultaniya complex in Cairo (probably built by Sultan

[5] is a modern term for a geographic region spanning (in clockwise order) north-eastern Iran, Turkmenistan, Uzbekistan, Tajikistan and north-western Afghanistan (O'kane, 1987).

Hasan, ca. 1356-60) was the origin of this form, which soon after spread in Iran (Meinecke, 1985).

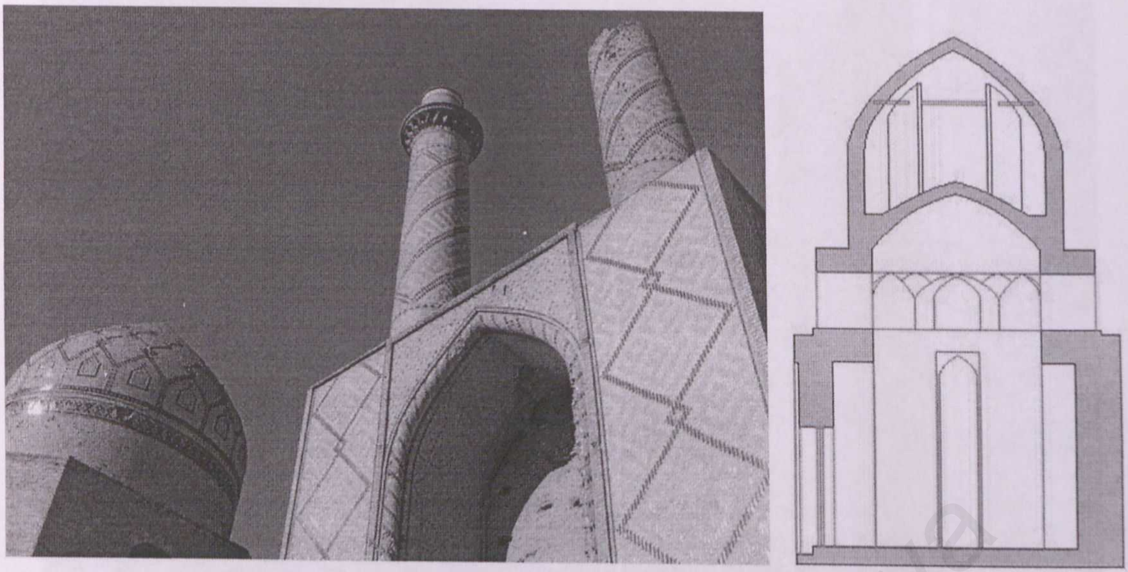
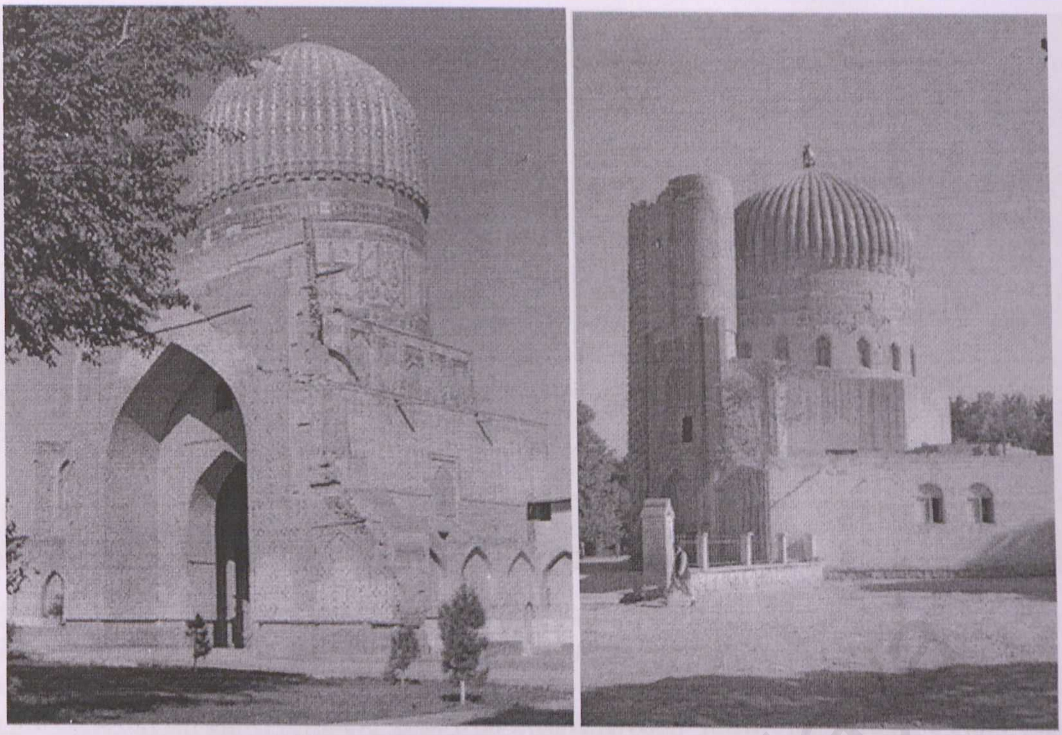


Figure 2.50: Sultan Bakht Aqa mausoleum with its internal stiffeners, Esfahan, Iran (Photo from www. flickr.com/photos/53047624@N00/2168410780/, uploaded by Hamzeh Karbasi; Cross-section after Memarian 1988).

International characteristic style of the Timurid domes, what is known with high drums and imposing the external features stabilized by projecting brick ribs, the use of meridians and the wooden struts (fig.2.51), was faded and altered significantly with the appearance of three specific local dynasties (Hillenbrand, 1999b): Saffavids in Iran (1501-1732 A.D.), Shaybanids in Central Asia (1503- ca. 1800 A.D.), and Mughals in India (1525-1858 A.D.; out of scope of this research).



(a) (b)

Figure 2.51: Uniform Timurids domical styles: ***a)*** *Bibi Khanum mosque, 1398/1405, Samarkand, Uzbekistan (Photo from www.archnet.org);* ***b)*** *Khawaja Abu Nasr Parsa mausoleum, 1460/1598, Balkh, Afghanistan (Source: The Ministry of culture & Youth Affair in Afghanistan).*

Soon later, the domical architecture were quickly blended with local styles after Timurids that were dominated by a skilful use of a diversity of building materials (vernacular architecture) and well-developed construction techniques existed in each region (fig. 2.52). The innovative approaches in the Islamic domical construction styles was obstacle and number of domes were considerably decreased by ending up the Saffavids (introduction of bulbous domes) and Shaybanids in the Middle East and Central Asia when it was longer survived in India up to the end of late Islamic era (Stierlin, 2002).

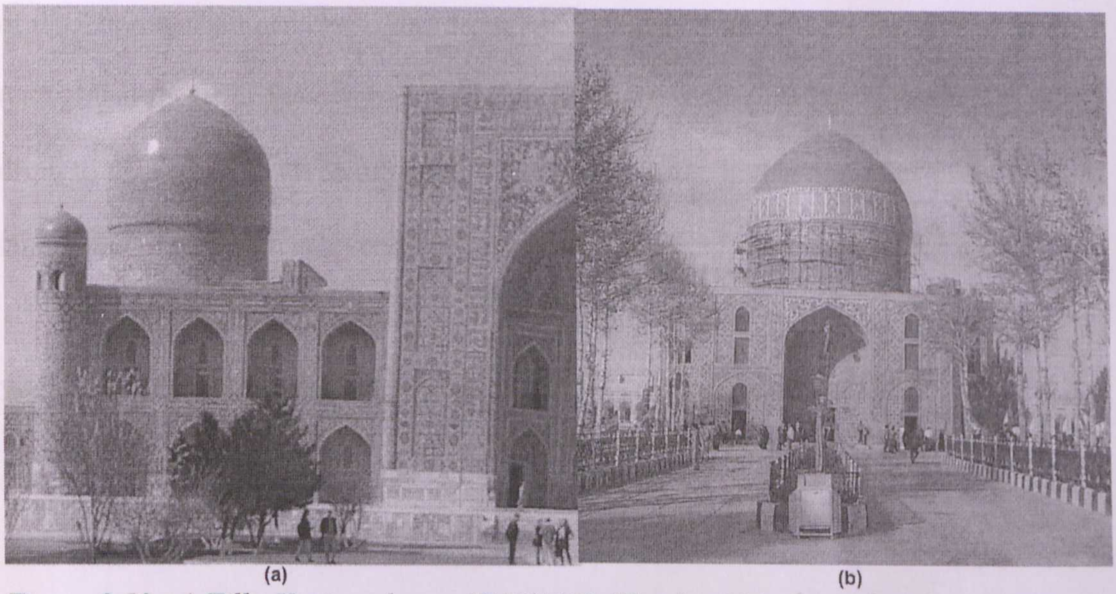


Figure 2.52: ***a)*** *Tilla Kari madrasa, 1746/1660 (Shaybanids), Samarkand, Uzbekistan (Photo from www.archnet.org);* ***b)*** *Khawaja Rabi mausoleum, 1617-22 (Saffavids), Mashhad, Iran (Source: www.trekearth.com/gallery/Middle_East/Iran/East/Khorasan_Razavi/photo1009543.htm, photo by Mehrdad Tadjdini).*

Morphologically, a pointed discontinuous double-shell dome consists of two shells; these are internal and external shells. There is a considerable distance between those shells. Total separation of the external and internal shells was achieved; higher drums usually rose directly from the roof. In this way, the thrust of the outer shell, which is rested on the drum, could be transformed into an impressive structure whose shape was independent of the building's interior.

According to the vertical sections of samples, their internal shells usually have pointed, saucer, and semi-circular and parabolic. Whilst form of their external shell, which is observed from outside, was designed in the pointed style.

All of such domes commonly were built over prominent mausoleums, mosques or *madrasa*. Their exterior surfaces are often embellished with the use of turquoise decorative tiles. In fact, considerable thought and effort were eminently given by the designers to make the building as high as possible by using the tall drum and changing the external shell geometry. The drum's body must be sufficiently massive to support e vertical thrust of the external shell, but its thickness diminishes from the top of the um to the apex. This type of dome is considered as the highest samples of the Eastern mpound domes with an average of height of 30 meters from the ground.

ch a dome consists of the distinct generic forms (fig.2. 53a):

- *The external shell*
- *The drum*
- *Meridian stiffeners or radial walls*
- *The internal shell*
- *Metal protection* (seldom)

addition, geometrically, the visual geometrical principles of this sort of domes are osely associated with the morphological aspects of the whole building as listed here: mmetry (in scale and aligned with axiality axe), proportion (hierarchy and levels, art-to-part), geometry (vocabulary's shapes), and axiality (scaling and orientation; *see* g. 2.53b) (Hillenbrand, 1994; Holod, 1988).

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of the external shell geometry. The drum's body must be sufficiently massive to support the vertical thrust of the external shell, but its thickness diminishes from the top of the drum to the apex. This type of dome is considered as the highest samples of the Eastern compound domes with an average of height of 30 meters from the ground.

Such a dome consists of the distinct generic forms (fig.2. 53a):

- *The external shell*
- *The drum*
- *Meridian stiffeners or radial walls*
- *The internal shell*
- *Metal protection* (seldom)

In addition, geometrically, the visual geometrical principles of this sort of domes are closely associated with the morphological aspects of the whole building as listed here: symmetry (in scale and aligned with axiality axe), proportion (hierarchy and levels, part-to-part), geometry (vocabulary's shapes), and axiality (scaling and orientation; *see* fig. 2.53b) (Hillenbrand, 1994; Holod, 1988).

To sum up, the pointed discontinuous double-shell domes were built based on specific geometric formula and special structural items which are introduced as the main characteristics of this type of the discontinuous double-shell domes. These also embrace the particular geometrical proportion, certain organization and specific internal stiffeners component. However, a research has been done on the pointed discontinuous double-shell domes by M. M. Hejazi (1997); so far, there exists not an exact research which highlights their various morphological properties and typical configurations.

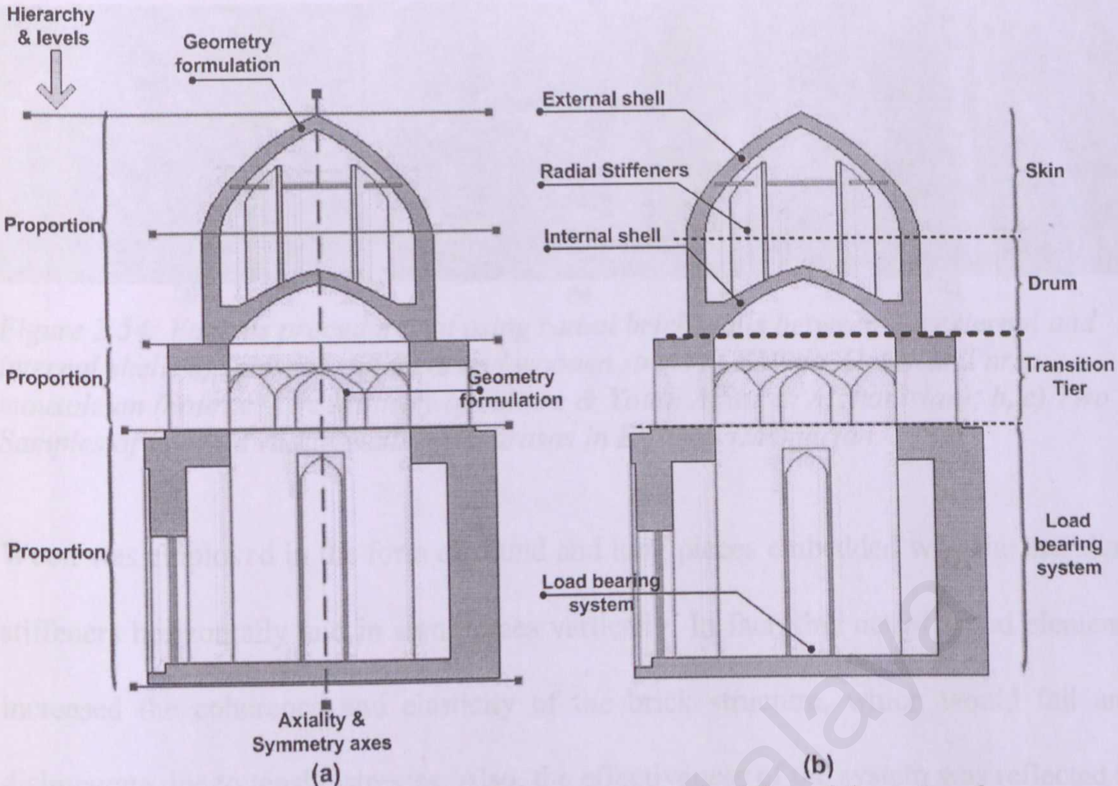

Figure 2.53: Generic forms and visual geometrical principles of the pointed discontinuous double-shell dome(Reproduced by Maryam Ashkan from Memarian, 1988).

2.6.1 Meridian walls or Internal Stiffeners

The fill between the two shells was a fundamental problem for the integrity of the whole system. For structural stability of the external shell, meridian walls or stiffeners are built in the space between the two shells. The height of the walls may vary from 2 to 20 meters and their thicknesses are not less than 50 cm, depending on the size of the dome. There can be appearing in as both main and secondary stiffeners with different sizes in a dome composition (fig. 2.54).

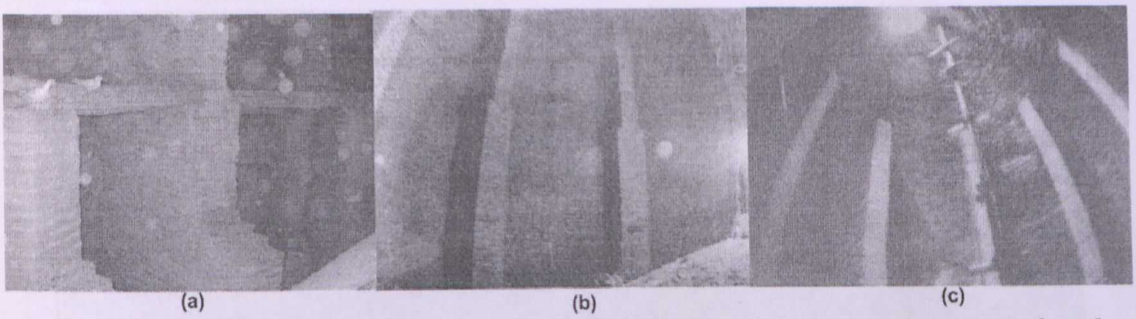

Figure 2.54: Various procedures of using radial brick walls between the external and internal shell: ***a)*** *Internal stiffeners and wooden struts of Khvaja Abu Nasr Parsa mausoleum (Source: The Ministry of culture & Youth Affair in Afghanistan);* ***b, c)*** *Two Samples of internal radial walls of madrasas in Esfahan (Memarian, 1988).*

Wood was employed in the form of round and long pieces embedded with the meridian stiffeners horizontally and in some cases vertically. In fact, this net of wood elements increased the coherence and elasticity of the brick structure, which would fail and disintegrate due to tensile stresses. Also, the effectiveness of the system was reflected in the fact that the building was not split by cracks in the long-term. There exist various types of such wooden systems in that their diversities fully conform to regional bonds and vernacular architecture (fig. 2.54-55).

The radial stiffeners play a crucial role in the stability of the double-shell dome; but, unfortunately their architectural configuration and structural concepts are fully obscure.

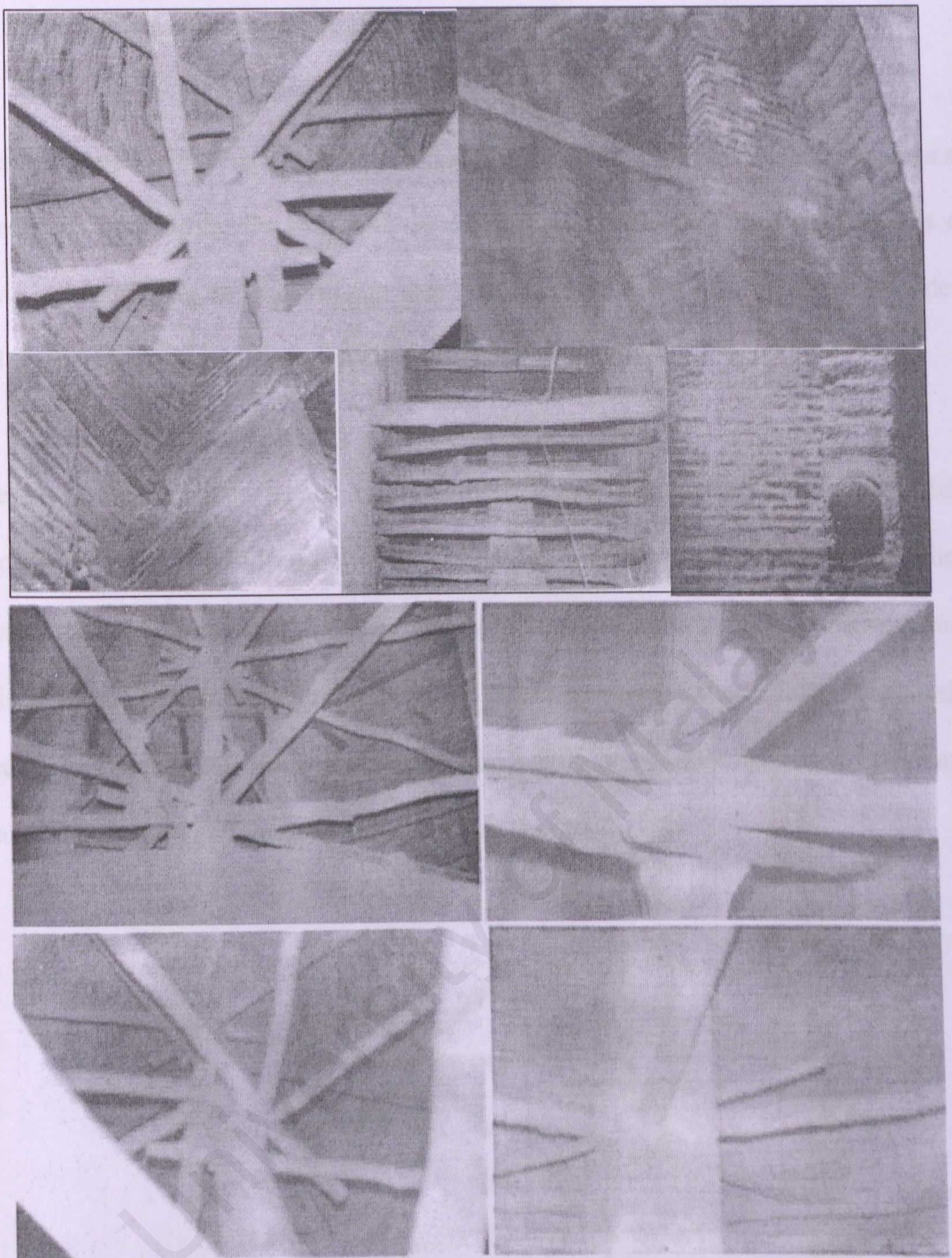

Figure 2.55: Different methods of settings of wooden struts and their locations in devised holes. (Memarian, 1988)

2.6.2 Metal Protection

The master builders faced difficulties in building the kick point of the dome the same as other parts of building. In fact, such *oculus* almost always remained on the crest of dome after finishing the construction shell. In order to fill this part, the master builders laid the horizontal brick layers instead of in radial direction.

Then, a vertical metal protection has been inserted after filling *oculi* (Oculus) by bricks in order to protect the top point of the dome against snow and rain. Likewise, there exists a clasp at its bottom which is used for stiffing in mortar and brick (fig. 2.56a). This metal protection structure consists of pieces of metal balls, a long metal stake, metal pipes, and metal drop-shape balls. The whole items encompass two holes as a result of assembling on the long vertical stake (fig. 2.56b).

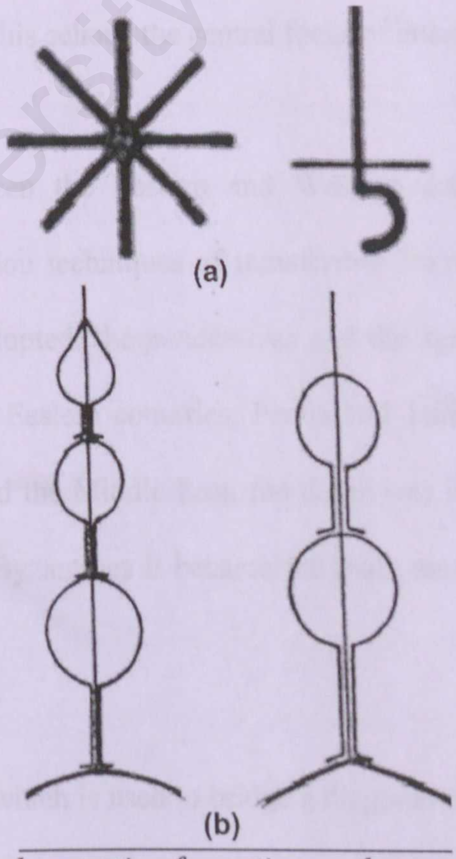

*Figure2.56: **a)** Clasp of metal protection for setting on the top of dome; **b)** Two common elements of metal protections (Pirniya and Bozorgmehri, 1992).*

2.7 Conclusions and Summary

The dome is one of the most efficient shapes in the world since it covers the maximum volume with the minimum surface area. It was preserved in many cultures and gradually translated into more permanent materials as family or royal tomb, a cult house, and so on. Therefore, there is no historical justification for the exact assumption of the dome's origins.

Logically, domes had been used to represent the different aspects of symbolism meanings based on the dominant thoughts of the specific period. On the other hand, the symbolic expression of domes was the main cause for their rapid development during the historic eras. Before the appearance of religion, it visually was a symbolic form of heaven and cosmic canopy. In Christian ideology, the domes were the natural symbol for the Universe and Creativity of God. The dome in Islamic architecture represents the Concept of Unity (*tawhid*). This echoed the central focus of attending to "***Allah***".

The main difference between the Eastern and Western domes may be highlight according to their construction techniques of transferring from the square to circular. Two main methods were adopted: the *pendentives* and the *squinches*. The essence of both, however, drives from Eastern countries: Persia and Turkey. On the other hand, when the Romans conquered the Middle East, the dome was incorporated into Roman architecture and under the Byzantines it became the main method of roofing Western monumental buildings.

The *squinch* is a mini-arch which is used to bridge a diagonal corner area whilst a dome needs the four mini-arches or arching for primary conversion from the square to the circular. *Squinches* are the main method of transition in Eastern architecture whilst *pendentives* became more common after the sixteenth century in Western architecture. Because of this there were various domical traditions in both the Western and Eastern architectures.

Historically, the dome seems to have developed as roofing for circular mud-brick huts in ancient Mesopotamia and Asur about 6000 years ago. In the 14th century, the Mycenaean Greeks built early tombs roofed with steep corbelled domes in the shape of pointed beehives (tholos tombs). Otherwise, the dome was not important in ancient Greek architecture. Nevertheless, the wooden domes were the common domical techniques in the Near East, especially in Syria and Palestine. There were various dome traditions in both the Western and Eastern architectures.

In the Western tradition, the domes seem to have developed as circular roofing in the 14th Century B.C. such as those of the Mycenaen Greeks with the steep corbelled domes. Then, the Romans developed the masonry domes by constructing the Temple of Pantheon (118-28 A.D.). The use of wooden domes, in parallel, was continued in the Early Christian periods for relatively small circular structure such as mausoleums, until the construction of the Hagia Sophia (532-37 A.D.) in the Byzantine (capital of Constantinople in Turkey).

The development of the Western domes reached its high level in the renaissance in Italy with the construction of the great Florence cathedral (1420-36 A.D.) which was built by the great architecture Filippo Brunelleschi. The notable baroque domes in northern Europe were built in London and Paris, respectively: Saint Paul's cathedral (1675--1711A.D.), and church of Saint Louis des Invalides (1676-1706 A.D.). Development of the Western domes was almost faded by the time of building the U.S. Capitol in Washington D.C. (1792 A.D.) and also the appearance of the modernism architecture movement.

In the Eastern tradition, the earliest known dome constructions, dating back to fourteenth and twelfth centuries B.C., are located in disparate regions such as China, Egypt, and Mesopotamia. Nevertheless, the development of dome buildings in the Eastern architecture can be studied according to the two particular parts: before the coming of Islam, and after the coming of Islam.

Before coming of the Islam, the oval arches and domes formed part of the tradition of masonry buildings, for instance, the invention of the arch in Asur and in Mesopotamia. The approximately egg-shaped forms were made regular through the use of practical geometry, perhaps about 2000 B.C., when the dimensions and the importance of the construction required it. Then, wooden domes were the common domical techniques in the Near East, specially, in Syria and Palestine.

Beyond the historical texts, the dominant features of the primary samples of Eastern domes are predominantly exposed in the configuration of these samples: Sanchi stupa (third B.C.E.) in India, Nyssa domical hall (first century A.D.) in Turkmenistan, Basilica of Hagia Sophia in Turkey, and Sassanian palace of Ardeshir in Iran (240 A.D.). In fact, the Middle East and Central Asia can be considered as a homeland of the appeaing and evolving of the Eastern domes.

After the coming of Islam and introduction of the wooden Dome of the Rock (621 A.D.), thousands of masonry domes were built throughout the Middle East and Central

Asia. Furthermore, the influence of the Islamic domes made itself felt in Western architecture as late as the nineteenth century.

The most dominant Islamic dynasties that had ruled during various periods in the Middle East and Central Asia are respectively addressed: Samanids (819-1005A.D.), Seljuks (1038-1194 A.D.), Ilkhanids (1256-1353 A.D.), Timurids (1370-1506 A.D.), Saffavids (1501-1732 A.D.), and Shaybanids (1503- 1800 A.D.).

In the Samanid dynasty, although no specific domical buildings had been built or even remained, but the Samanid mausoleum, as the primary sign of collaboration of the mathematicians, is the most important architectural achievement of this dynasty. Soon after appearing of Seljuks, , the invariable practice of the dome constructions in are seen in these distinct two types: a cylindrical tower topped either with one or two shells. Also, the various samples of one shell domes are other aspects of the Seljuk architecture. Others worth monuments of this period are the various types of conical discontinuous double-shell domes in both Turkey and Persia.

After architecture went into deep decline following by several Mongol invasions and their successor, Timur (hence a gap in the domical construction), the material culture of the Middle East and Central Asia flourished again, led by the Ilkhanids (in Iran) and Timurids (in Uzbekistan), later on. The various types of pointed discontinuous double-shell domes are appeared a result of these periods. The construction of conical domes, however, had still continued as well.

International characteristic style of the Timurid domes, which is well-known due to its high drums, imposing their external features, projecting brick ribs, the use of meridian walls and wooden struts, was faded and altered significantly by appearing three specific local dynasties: Saffavids in Iran (1501-1732 A.D.), Shaybanids in Central Asia (1503-ca. 1800 A.D.), and Mughals in India (1525-1858 A.D.). Meanwhile, during the rule of the Shaybanids in Uzbekistan, the construction of the pointed discontinuous double-shell domes reached its high level of development so that it was never surpassed in any other periods.

As results, the domical architecture was quickly blended with local styles after the Timurid era that was dominated by a skilful use of a diversity of building materials (vernacular architecture) and also well-developed construction techniques existing in each region. The innovative approaches in the Islamic domical construction styles were obscured and the number of domes considerably decreased after the end of Saffavid and Shaybanid rule in the Middle East and Central Asia; although the Eastern dome tradition survived much longer in India up to the late Islamic era.

Structurally, the dome can be considered as a structural consonance and a hierarchy of ordered parts, that is, the relationship between the internal space and structural mass and/or positive and negative spatial spaces. Morphologically, the Eastern dome consists of the four general features, namely, vocabularies; these are supporting system, transition tier, drum, and shell (s).

- ***Supporting system:*** there is a defined concern for the load bearing items, that is, the essential structural system which must fulfill the static requirements of the building by transferring the load to the ground;
- ***Transition tier:*** the structural feature designed to take the horizontal thrust of the dome and then transfer it to the lower load bearing system. This architectural device

can be constructed based on the two main forms: *pendentives* from the Byzantine architecture and *squinches* from the Sassanid Empire onwards;

- ***Drum:*** is a cylinder form on which the shell is rested; and
- ***Shell(s):*** this architectural item was often used synonymously in several climes.

Except for the earlier samples, the interior and exterior shells often were unlike following the appearance of the double-shell domes. In fact, the shell is a total reflection of the dome dynamism throughout historic eras.

Of course, the role of proceeding the pre-Islamic monuments and characteristics cannot be overlooked in the final definition of dome vocabularies in the Islamic dome architecture such as, those monuments of the Hindus, Zoroastrians, and Christians. In fact, a brief review of these domes revealed their multiplicity and the unity of the earliest samples.

Typologically, based on how two shells (internal and external) are arranged together, the Eastern domes can be categorized into: one shell (the earliest type of the Eastern domes), two shells, and three shells. The latter one may involve as a developed constitution of the double-shell dome in such a way that one shell almost always plays either a decorative or structural roles. Regarding the double-shell types, based on how these two shells are composed together, two subdivisions have been defined: continuous and discontinuous, respectively.

In continuous double-shell domes, sometimes, there exist no considerable distance between the shells, or they are connected by brick connectors, but so often the distance between shells is small. The continuous two shell domes can be called "an evolving stage" from the one shell domes to the two shells domes in development of Islamic dome architecture; the construction of the one shell domes had recurrently been continued up to the late Islamic era.

In discontinuous double-shell domes, there is a considerable distance between the two shells. The discontinuity may start either from the base or from the top of the drum which is considered higher than the other types of the Islamic domical typologies. The discontinuous double-shell domes are specified according to their external shell shapes into the four specific typologies: conical, pointed, bulbous and finally Mongolian.

In contrast to complex geometric characteristics of both pointed and bulbous domes, the conical typology of the discontinuous double-shell domes exhibited a simple configuration concept. Despite the confined number of the bulbous type, the pointed typology historically contains the majority of the discontinuous double-shell domes throughout the Middle East and Central Asia. The exhaustive configuration of the pointed typology showed its superior compositional development of the architectural conceptualism. The bulbous domes (also, named "onion" in some textual literature) are the most prominent shape of the discontinuous double-shell domes and the last generation of the Islamic domes which appeared since the Saffavid dynasty (the 16th century) in the Middle East.

The most common prototype of the discontinuous double-shell domes compositionally consist of external shell (the most important component and most visible part of the dome), high drum, internal shell, and radial stiffeners within the wooden struts. Internal stiffeners with the wooden struts are structurally built in the space between the two shells for filling the empty space mainly to support the external shell. In fact, radial (meridian) stiffeners are the only distinct components of the bulbous and pointed typologies in comparison to the one shell samples and conical discontinuous double-shell domes.

There is an architecturally specific factor, called, "the composition of the radial brick walls with the wooden strut" that had been recognized in both the bulbous and pointed samples. The pointed typology of the discontinuous double-shell dome has been selected for detail consideration due to its critical role and extension beyond the Middle and Central Asian countries.

It is demonstrated that architectural configurations of Eastern domes consist of the specific arrangements of elements. Morphologically, in terms of analysis of Islamic dome characteristics, proposed methods have to rely certainly on estimations of their components. From the geometrical point of view, in terms of analysis of the pointed discontinuous double-shell domes, it seems necessary to develop a specific approach with enough shape flexibility to cover the majority of samples of such domes. In Chapter Three, these methods and selected samples would extensively be elaborated and presented.

Chapter 3
Research Methodology and Process

3.1 Introduction

According to the investigations of history of traditional domes in the Chapter Two, it was demonstrated that there have existed a wide variety of domes throughout historic epochs in the Middle East and Central Asia. In this regard, the combination of methods seems necessary for analyzing both their morphological and typological characteristics. Because of this, the Research process totally consists the two parts including multifold approaches qualitatively.

Various studies have highlighted the different aspects of Islamic domes such as their historical grounds and/or their general configurations (Grabar, 1963; Hejazi, 1997; Michell, 1978; O'Kane, 1998; Pope, 1971; Smith, 1971; Stierlin, 2002). Nevertheless, much is still uncertain and vague, ***especially, with respect to the crucial problem of their common morphological aspects, typical patterns of their architectural components since the early Islamic era until the late Islamic epoch*** which would be considered in the Part One of this Research.

In respect to the second part of Research, the pointed discontinuous double-shell domes found out as the common domical forms synonymously amongst the Middle East and Central Asian countries. Despite several existing studies on Islamic domes and specific relative meanings, ***the pointed discontinuous double-shell domes have still had incompletely well-known regarding their morphology, sub-typologies, geometrical contexts, and even associated terminologies***. Ways of redressing these existing gaps in knowledge of dome structures are considered in the Part Two of this Research.

Also, it specially focuses on the ground of approaches for achieving those Research objectives that have been employed for gathering data and analyzing issues. The aims and advantages of each method partly have been elaborated.

The first part of this chapter specifies estimations of several commonalities of Eastern Domes such as, their morphological survey, typological survey, and estimation of distributions of these general vocabularies[1] in different zones of the Middle East and Central Asia. In this sense, a specific table has been provided to estimate fifty three selected samples based on the comparative survey.

Also, specific terms were used in tables for calling the morphological and typological surveys of the Eastern Domes, that is, the "*Visual Language* " of the Eastern Domes which is included synonymously as their associated vocabularies (morphological aspects) and grammars of their configurations (typologies). Nevertheless, results from the Part One are usable and necessary for considering the pointed discontinuous double-shell domes in the second Part.

In the Second Part, the chapter mainly concentrates on detailed estimation of the pointed discontinuous double-shell domes with focus on their geometrical considerations. Because of this, multifold approaches have been used including morphological survey, typological survey, geometrical survey, construction survey and structural survey.

Regarding geometry survey, using the *al-Kashi* geometrical essences provided a ground for generating a four-centered general profile based on new geometric parameters. In fact, it is also used to deduce the geometric commonalities of the typical formal

[1] Refer to the Chapter one- page 26 for the extensive elaborations of both "vocabularies and typologies" of dome.

languages of typologies of such domes. Common geometric prototype for samples' profiles are then generated and formulated according to the proposed parametric system. In addition, the shape-patterns of the derived morphology of such domes are finally derived and presented.

To understand structural vulnerability of such domes, the four common prototypes are selected and modeled into the ABAQUS software. Their structural safeties are considered by looking for admissible equilibrium states for only dead loads for understanding approximate boundaries of the shells where primary cracks probably may occur. Figure 3.1 shows Research approaches, steps and processes that are extensively elaborated in the following sections.

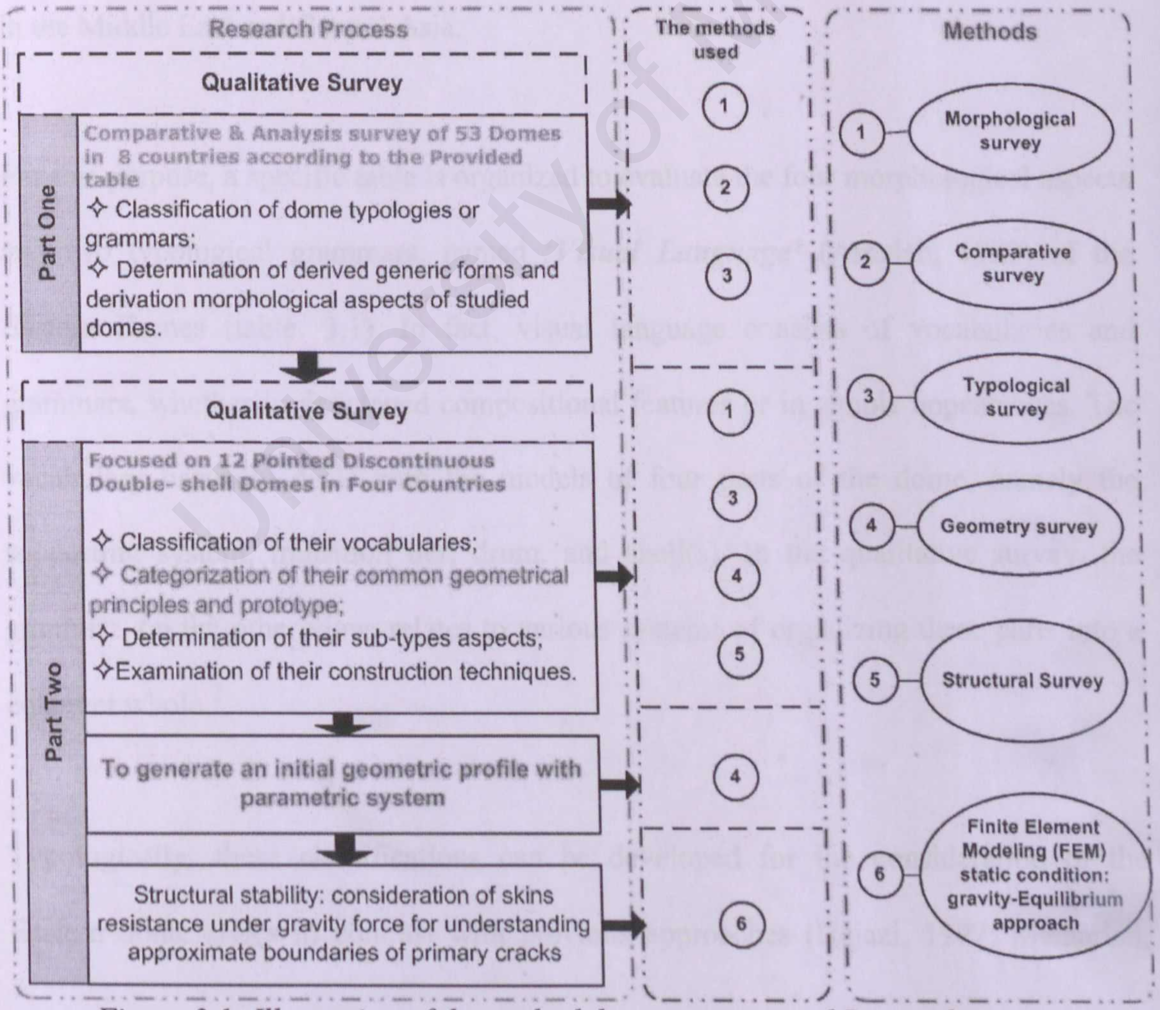

Figure 3.1: Illustration of the methodology structure and Research process.

3.2 Part One: Comparative Survey, Vocabulary survey, Grammar survey

In order to recognize the various appearances of the Eastern Domes qualitatively, comparative, morphological and typological surveys of fifty three samples have been organized, respectively. The distributions of both vocabularies and grammars of these samples' (Ardalan, 1973, 1980) through the studied countries (zones) had been compared.

This comparative survey of these examples made it possible to catalogue the relative occurrence of the commonality of their forms and developments which were found in the fragments of the architectural design of Eastern Domes over historical investigations in the Middle East and Central Asia.

For this purpose, a specific table is organized to evaluate the four morphological aspects and two typological grammars, named ***'Visual Language'*** (Ardalan, 1980) of the Eastern Domes (table. 3.1). In fact, visual language consists of vocabularies and grammars, whether in developed compositional features or in simple appearances. The vocabulary basically deals with the models of four parts of the dome, namely the supporting system, transition tier, drum, and shell(s). In the qualitative survey, the grammar, on the other view, relates to various systems of organizing these parts into a coherent whole [2].

Typologically, these classifications can be developed for the consideration of the Eastern dome styles in contrast with previous approaches (Hejazi, 1997; Memarian,

[2] Refer to the Chapter one- page 26 for the extensive elaborations of both vocabularies and grammars.

1988) by introducing two new meanings: simple and compound[3]. These visual languages are arranged in the four tables based on their various identified shapes.

[3] These meanings are comprehensively elaborated in Sections 3.2.2.

Table 3.1: Illustration of the organized table for comparative survey.

			Qualitative Survey															
			Morphological Survey											Typological Survey				
			Generic forms (Vocabularies)											Dome Typology or Generic form Grammar				
			Supporting System				Transition tier		Drum		Shell			Simple		Compound		
No.	Locale	Name	Cylinder	Square with bearing wall	Square with lateral vault	Other	Pendentive	Squinch	Cylinder	Many-Sided	One	Two	Three	With drum	Without drum	With drum	Without drum	Century of construction A.D.

Keys: A Conical shell ? Insufficient information

These provided tables were respectively filled by evaluating samples, qualitatively-comparatively, in each defined zone. In terms of incomplete information about samples, the sign of question mark (?) was used beside those circular signs, whenever the information of samples was incomplete. In order to underline the conical domes, the sign of (A) was used beside the circular sign of shell vocabulary. Note that the visual language including vocabularies and grammars, which would be presented in the following sections, is only 'architectural expressions' whereby the Eastern domes can be analyzed.

3.2.1 Morphological Survey of the Eastern Domes

Based on the historical background considerations, the common configuration (generic forms) of the Eastern Dome consists of supporting system, transition tier, drum and shell. They are set out in Table 3.1 based on their various recognized shapes as follows:

- ***Supporting System:*** cylinder, square with lateral vaults, square with bearing walls, and others dedicated to any special shapes of the load bearing system;
- ***Transition Tier:*** *pendentives* and *squinches* which are the basic formations of this element of dome;
- ***Drum:*** circular and many-sided; and finally
- ***Shell:*** one shell, double shells, and triple shells.

The relation of these generic forms, their sequences in the dome configuration, and compositional possibilities are classified in Figure 3.2.

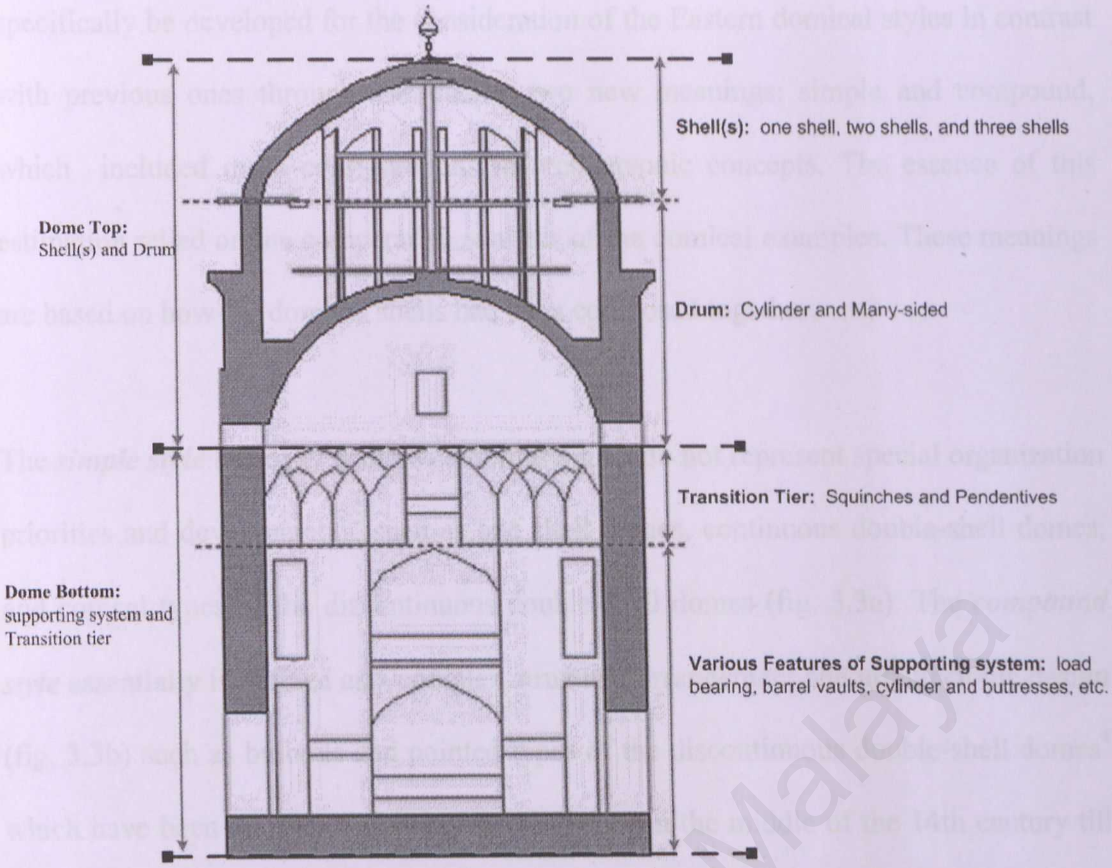

Figure 3.2: Illustration of the generic vocabularies or morphological aspects of the Eastern Domes and their settings in the dome composition (Ashkan and Yahaya, 2006). Cross-section reproduced by Maryam Ashkan from (the Iranian Cultural Heritage Organization documentation centre (ICHO))

Using Table 3.1, distributions of these vocabularies are qualitatively estimated through different regions of the Middle East and Central Asia. The essence of these estimations relied on the comparative analysis of the domical examples. As a result, their common analogical patterns and architectonic aspects also are qualitatively listed and addressed in Chapter Five.

3.2.2 Typological Survey of the Eastern Domes

The domical grammars (or typological features), however, can be elaborated as distinct ways of components' structuralism in the dome configuration. Nevertheless, the Eastern Domes are commonly classified based on their shell organization (e.g., double shells, discontinuous double-shell etc.) (Hejazi,1997; Memarian, 1988). This classification can specifically be developed for the consideration of the Eastern domical styles in contrast with previous ones through introducing two new meanings: simple and compound, which included more configurations in architectonic concepts. The essence of this estimation relied on the comparative analysis of the domical examples. These meanings are based on how the domical shells had been composed together.

The ***simple style*** basically deals with domes which do not represent special organization priorities and developments, such as one shell domes, continuous double-shell domes, and conical types of the discontinuous double-shell domes (fig. 3.3a). The ***compound style*** essentially is defined as a complex structural arrangement and architectonic design (fig. 3.3b) such as bulbous and pointed types of the discontinuous double-shell domes[4] which have been the major styles of domes between the middle of the 14th century till the end of 18th century.

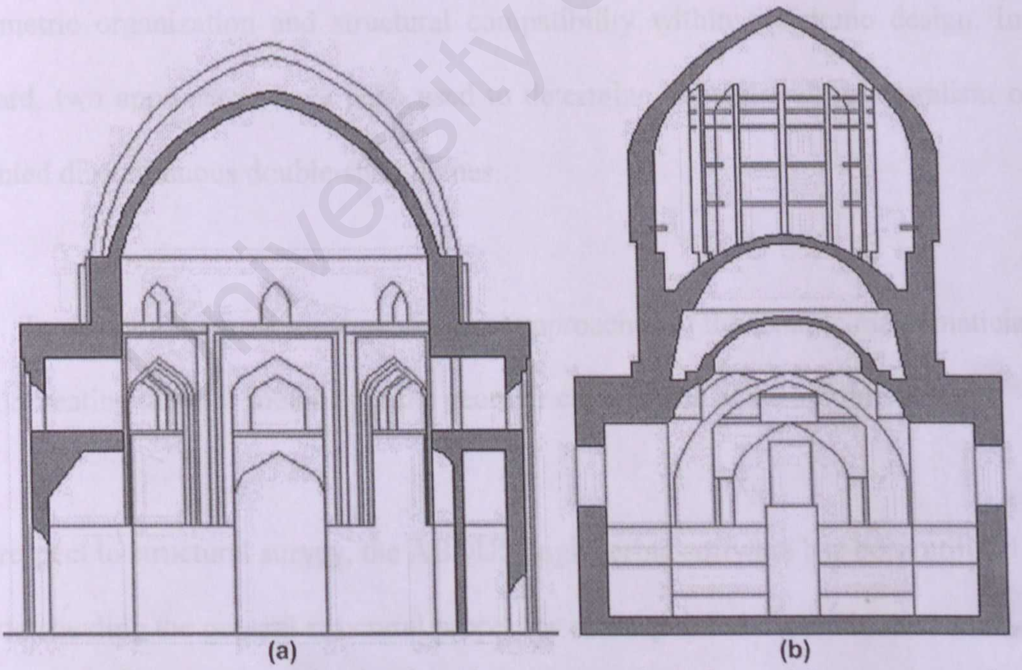

Figure 3.3: Illustration of the developed meanings of typological features: simple and compound. Cross-section reproduced by Maryam Ashkan from (Memarian, 1988; Hillenbrand, 1994)

[4] The discontinuous double-shell domes are basically classified based on forms of their external shells to bulbous (onion) types, pointed types, and conical types (Ashkan and Yahaya, 2009).

Using table 3.1, distributions of these grammars are qualitatively estimated through different regions of the Middle East and Central Asia.

3.3 Part Two: Geometrical Survey, Vocabulary Survey, Grammar Survey, Structural Survey

In order to analyze the pointed discontinuous double-shell domes, multifold approaches have been structured, including morphological survey, typological survey, geometrical survey, and structural survey. The approach for morphological survey, mainly, proceeded as same as the part of Research; While the typological survey is completely structured based on the geometrical survey.

The concept of geometrical approach, nevertheless, relies on the importance of the geometric organization and structural compatibility within the dome design. In this regard, two approaches have been used to determine geometrical structuralism of the pointed discontinuous double-shell domes :

- To develop the traditional geometrical approaches of the Islamic mathematicians for creating the new method for the geometrical analysis of such domes.

In respect to structural survey, the ABQUS engineering software has been utilized for understanding the general structural properties of the pointed discontinuous double-shell domes.

In terms of architectural survey, twelve case studies of the pointed discontinuous double-shell domes have been selected for more detailed analysis. Accordingly, the morphological aspects of these samples have been examined and considered based on their plans, photographs, and, whenever possible, site visits to determine and list the following aspects: traits of shells, drum, transition tier concept, load bearing system, and characteristics of internal radial stiffeners.

The derived shape-patterns are classified into the specific documents belonging to the studied samples. Also, some of the wrong drawings were revised and redrawn based on the correct information, especially regarding the setting of internal stiffeners and their arrangements between two shells. Each document consists of the related sections, plan, geometrical design analysis based on the new initial shape, and 3D modeling.

3.3.1 Dome and Geometry

It seems necessary primarily to highlight the relation between dome and geometry before studying the historical background of using geometry in Islamic dome design (Reynolds, 2001). The author believes that geometry in architecture is an implement for correlation and consistency, not only limited to the architectural design exclusively, but also used for establishing virtual absorb complexity, subtlety, and so forth, in aesthetics and art. The use of circular shape and its geometric parameters for creating "great formula" in dome design is essentially related to the idea of the builder when he had decided to construct a dome. It is strongly similar to the ideology of the human existing in the world (some of these philosophical discussions are beyond the scope of this thesis).

3.3.2 Historical Background of Roles of Mathematicians in the Dome Design

In the development treatise of the Islamic discontinuous double-shell domes, the role of the mathematicians cannot be overlooked. In general, Islamic mathematics, in contrast with the Greek mathematics, can also be called "the mathematics of practitioners" because of the close relationship between theory and practice (Özdural, 2000). Its proper demonstration can be derived from the works of al-Buzjani's student who recorded contexts of his meetings with master builders and architects to discuss solutions to construction problems (Özdural, 1995).

The locations of Islamic mathematic scientific centers were in the present-day Iran and Iraq. The main languages used by mathematicians for writing mathematical treatises were Persian and Arabic (principal languages like Latin in Medieval Europe), and Turkish (more translation versions). Because of this, the mathematics used is often called "Arabic mathematics".

It is interesting to observe how the mathematicians had to take into consideration the master builders' objectives for using geometry in design as well as how the artisans had to realize the differences between precise and approximate approaches (Katz, 2007). In fact, the main efforts aimed to define and formulate "an exact geometric method" rather than to determine certain proportions, the dome designs, and even for the arch and vault compositions.

The primary textual signs of their assistance can be seen in the Ismail Samanid mausoleum in Bukhara which was built in the early Islamic era (fig. 3.4); its formation was entirely designed by the geometrical principles of three celebrated mathematicians: *al-Khorezmi*, *al-Fargani*, and *Ibn-Sina* (Askarov, 2007; Pope, 1971).

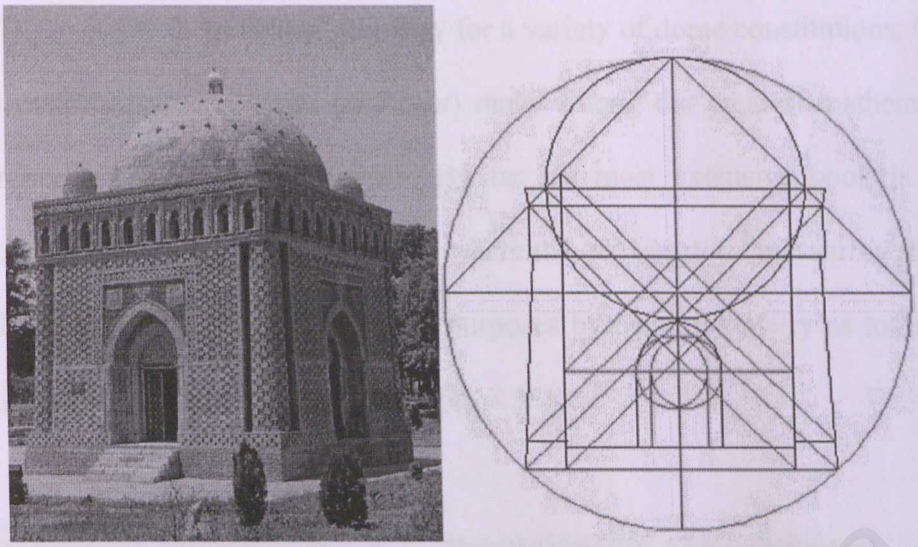

Figure 3. 4: Geometric design of composition of the Ismail Samanid mausoleum, Bukhara, Uzbekistan. Geometric composition reproduced by authors from Pope (1971). Photo from (www.sacred-destinations.com/uzbekistan/bukhara-ismail-samani-mausoleum.htm.)

A descriptive geometry method was used by Abu Sahl al-Quhi (circa. 1000) for projecting circles on the sphere into the equatorial plane. Then, he rendered them back onto the sphere in an outstanding visual manner. However, it would seem that he was not interested in the practical mathematics (O'Connor and Robertson, 1999). Another known text is "*Kitab fi ma yahtaj ilayh al-kuttab wa'l-ummal min 'ilm al-hisab*" (a book on the geometric constructions necessary for craftsmen), written by Abu'l- Wafa Buzjani (circa. 1000) for practical use.

Although neither the specific domical geometry nor the related information was mentioned in this book, his particular geometric methods have helped solve problems by simply using a ruler and a fixed compass (Jazbi, 1997). The long absence of developments ca. 1000 until ca. 1400 was the result of the genocide of scientists by the troops of the Mughals and Timur (Stierlin, 2002).

The Buzjani method was developed by the celebrated mathematician *al-Kashi* (1390-1450 A.D.) to create the practical geometry for a variety of dome constitutions. Ghiyath al-Din Jamshid Mas'ud Kashani (*al-Kashi*) ranks among the greatest mathematicians and astronomers in the Islamic world. By far his most extensive book is *Key of Arithmetic* (Book IV), on "Measurements" where the last chapter, "measuring structures and buildings"', was written for practical purposes by using geometry as tools for his calculations (Dold-Samplonius, 1992, *see* fig. 3.5b).

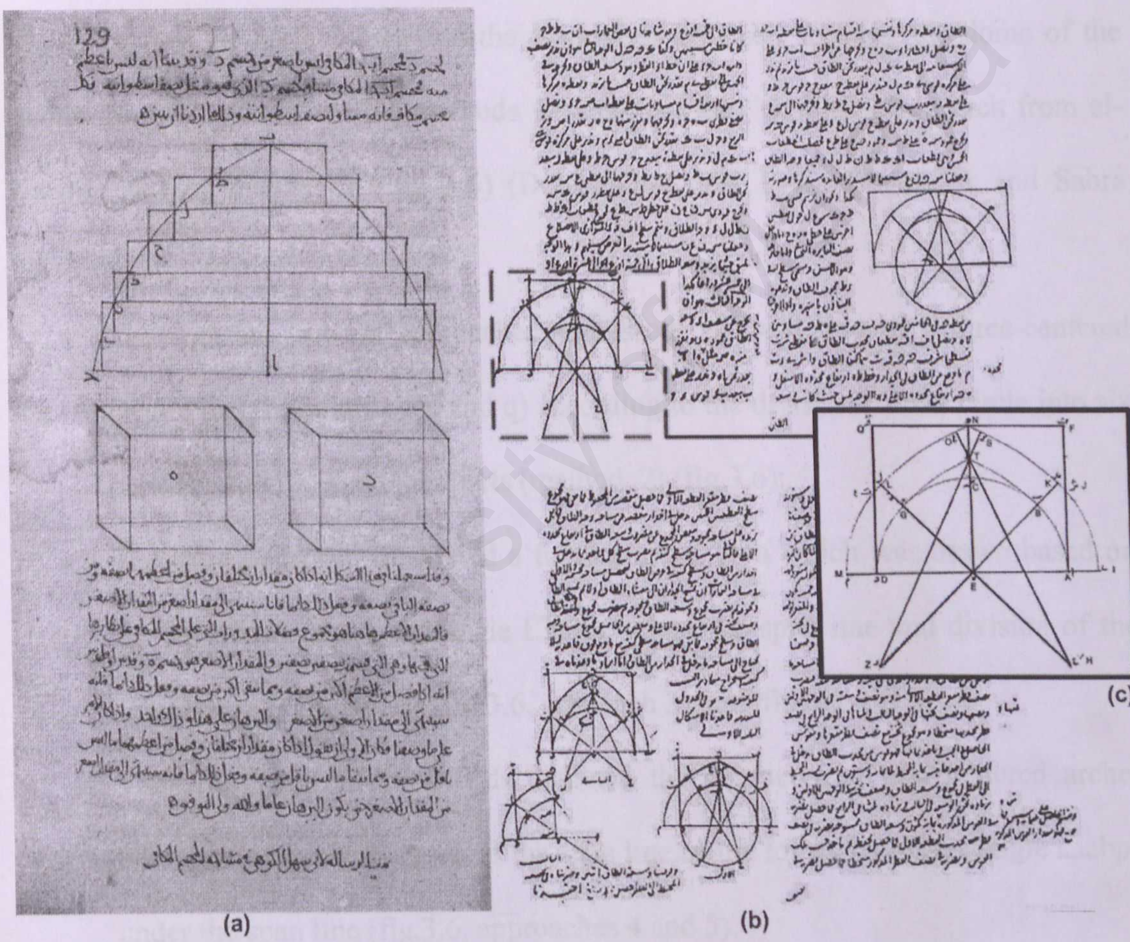

*Figure 3. 5. Traditional approaches for designing a dome's external shell: **a)** some geometrical shapes from Suhayl al-Quhi's book "Fî istihraci mesaha al-muhassama al-maqafi or Risala-i abu Sahl" (Suleymaniya library, Ayasofya- 4832); **b)** a page of al-Kashi's book, IV Manuscripts (Memarian, 1988; Memarian and Pirniya, 2003); **c)** Dold-Samplonius re-drawing of the al-Kashi method (Dold-Samplonius, 2000).*

As *al-Kashi* remarks in the *Key of Arithmetic* (Dold-Samplonius, 2000): "The specialists merely spoke about this measuring for the arch and the vault and besides that it was not thought necessary, but I present it among the necessities together with the rest, because it is more often required in measuring buildings than in the rest."

There are several translations of his book in both Persian and English languages such as, Dold-Samplonius (2000, 1992) and Memarian (1988; 2003) who have discussed several aspects of the *al-Kashi* calculation principles[5]. They include his good methods in approximating the surface area and the volume of the shell forming the dome of the *qubba*. She elaborated on five methods for drawing the "profile" of an arch from al-Kashi's *Key of Arithmetic* (fig. 3.6) (Dold-Samplonius 1992; Hogendijk and Sabra 2003).

- The first and second approaches addressed the designing of a three-centered profile (centre points o, p, and q) according to the divisions of the circle into six parts (method 1) and eight parts (method, 2) (fig.3.6);
- The third approach illustrated a four-centered arch which was drawn based on the construction of a rectangle □abpq under the span line and division of the span line into eight parts (fig.3.6, approach 3); and finally
- The fourth and fifth methods depicted the geometry of two-centered arches based on either the division of the span line or the formation of rectangle □abpq under the span line (fig.3.6, approaches 4 and 5).

[5] Refer to Appendix A for more discussion.

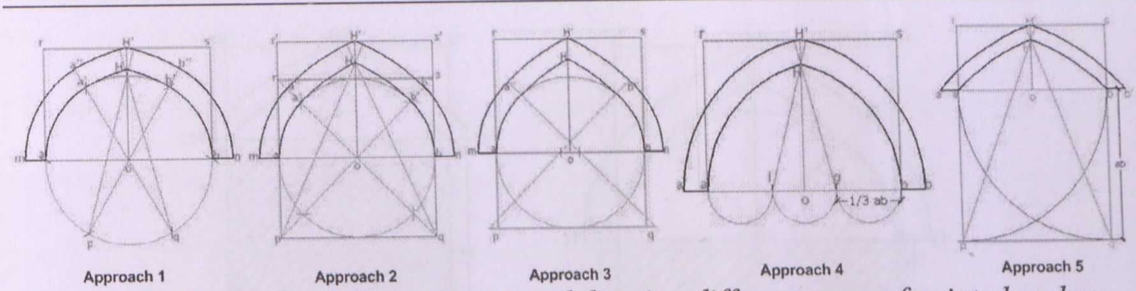

Figure 3. 6: Five methods for designing and drawing different types of pointed arches from Kâshânî's Key of Arithmetic. (Reproduced by author from Hogendijk and Sabra, 2003; Dold-Samplonius, 1992, 2000, Taheri, 2009).

The essence of *al-Kashi's* drawings, which were frequently employed for designing different types of arches, vaults, and domes (Dold-Samplonius, 1996), can be listed and concluded as follows:

- Using the variety of procedures of the division systems (divisions of circles in the approaches 1 and 2, the specific constructions of rectangles under the span line in the approaches 3 and 5, division of the span line into particular parts in the approach 4) for getting the centre points to draw the appropriate shapes of arcs (fig. 3.7). The upper part of the profile (third and forth arcs) clearly showed a longer radius compared to the lower part of the profile (first and second arcs). Centre points of these arcs are located far from the profile than the lower part;

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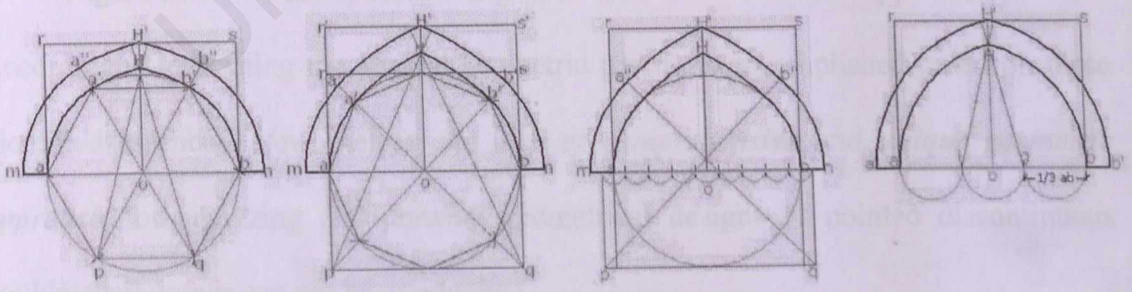


Figure 3. 7: The use of various division systems in the al-Kashi geometric methods.

- The specific constructions of rectangles under span lines (Approaches 3 and 5) (fig. 3.8);

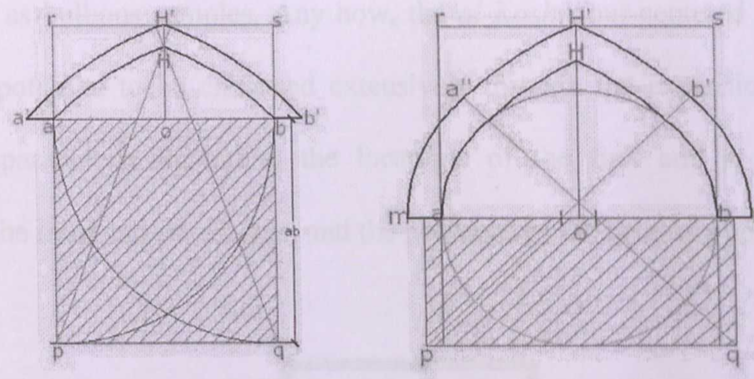


Figure 3. 8: The construction of rectangles under the span lines to get the centre points of the upper parts arcs.

- Employing the different types of profiles (two-centered, three-centered and four-centered) for designating the distinct types of the arch profiles for various building usages; and
- Using certain angles 45' and 60' (approaches 1 and 2) (fig. 3.9).

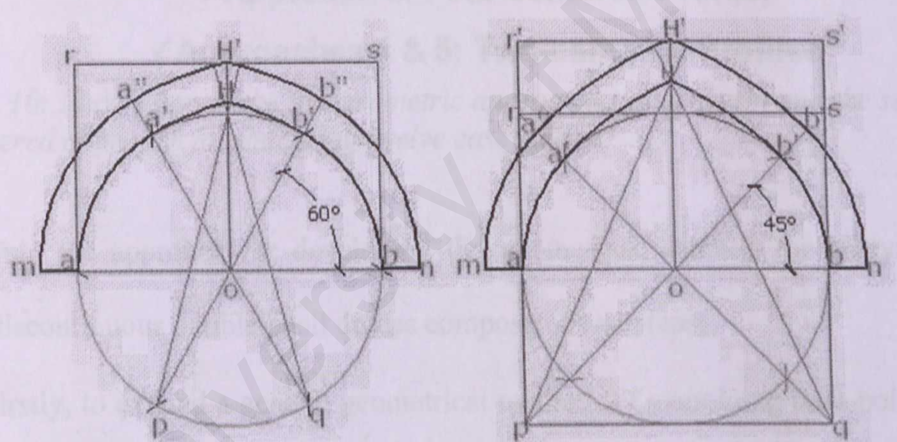


Figure 3. 9: The use of certain angles 60' and 45' in al-Kashi approaches.

Accordingly, generating the general geometric profile is accomplished based on these identified essences. Nevertheless, ***the lack of comprehensive and unique geometric approach*** for analyzing and drawing geometrical designs of pointed discontinuous double-shell domes can not be overlooked.

The *al-Kashi* geometric approaches were used for designing common shapes of profiles of arches, vaults, and domes at that time, and hardly covered the majority of geometrical designs of the Islamic dome compositions with their different attributes in various periods such as bulbous samples. Any how, the *al-Kashi* four-centered profile (fig. 3. 10) has the potential to be enhanced extensively through the expansion of the three geometrical parameters, including the locations of the first and second arcs, the locations of the third and fourth arcs, and the positions of the breaking points.

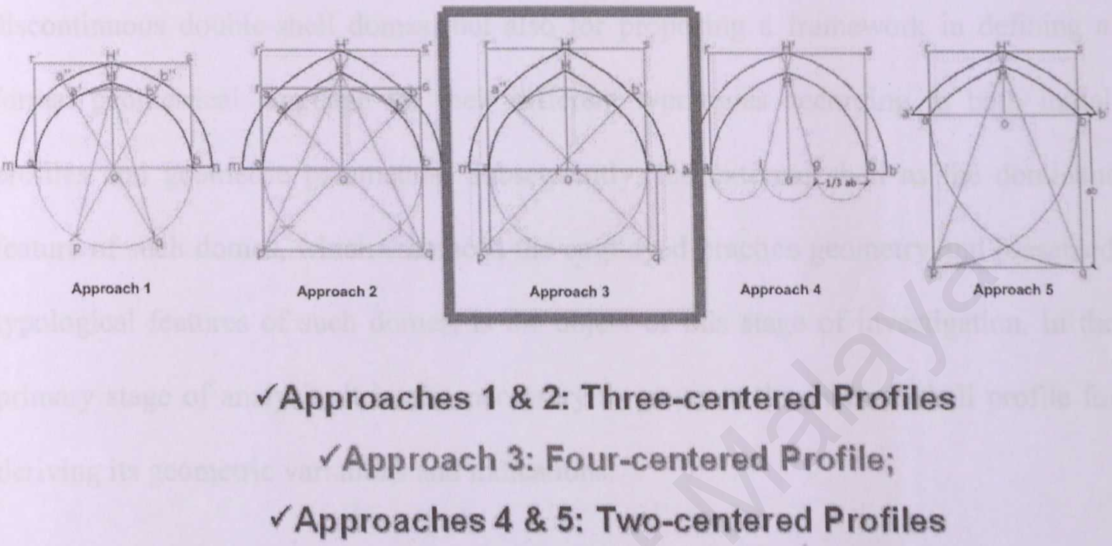


Figure 3. 10: Illustration of the five geometric approaches of al-Kashi and the selected four-centered approach for analyzing twelve case studies.

To sum up, the approach for developing the geometrical method for analyzing the pointed discontinuous double-shell domes compose of two steps:

- Firstly, to expand a general geometrical method for examining both pointed and bulbous domes; then
- Secondly, to re-construct and re-formulate this generated profile for deriving the common geometrical prototype of the pointed domes, according to twelve case studies.

3.3.3 The Developed Geometrical Method for General Analyzing the Discontinuous Double-shell Domes

A comprehensive geometric method with new parameters is required to be utilized as a tool, not only for analyzing the configuration patterns of the various types of discontinuous double-shell domes, but also for proposing a framework in defining a formal geometrical language for their different typologies according to both initial profiles and geometric parameters. Subsequently, the external shell as the dominant feature of such domes, which embraced the employed practice geometry and presented typological features of such domes, is the object of this stage of investigation. In the primary stage of analysis, it is also necessary to generate the internal shell profile for deriving its geometric variations and indications.

The key in understanding the geometric composition of the external shell is in studying the dome cross-section when its thickness diminished (Huerta, 2006). This so-called '*profile*' forms the basis of the dome geometric design. It consists of four small arcs, namely, the lower part (first and second arcs) and the upper part (third and fourth arcs) (fig. 3.11a, b). Its fundamental properties consist of the '*span*' and the '*rise*'. The horizontal distance between the two supporting members is called the span whilst the rise is the vertical distance from the middle center of the span line to the tip of the profile (fig 3.11b). The span is the origin and fundamental to all the rules for obtaining the proportion values.

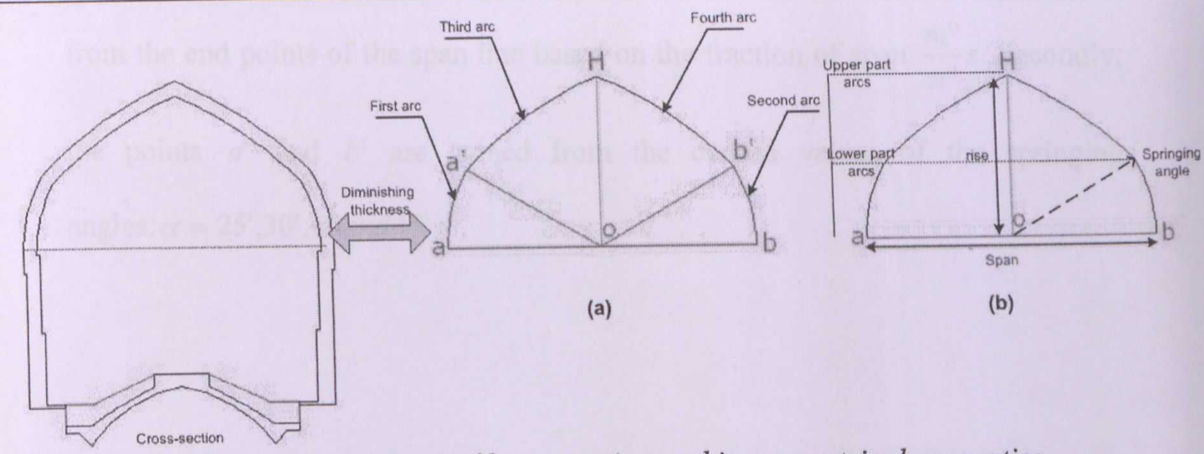


Figure 3.11: Illustrations of the profile generation and its geometrical properties (Ashkan and Yahaya, 2009).

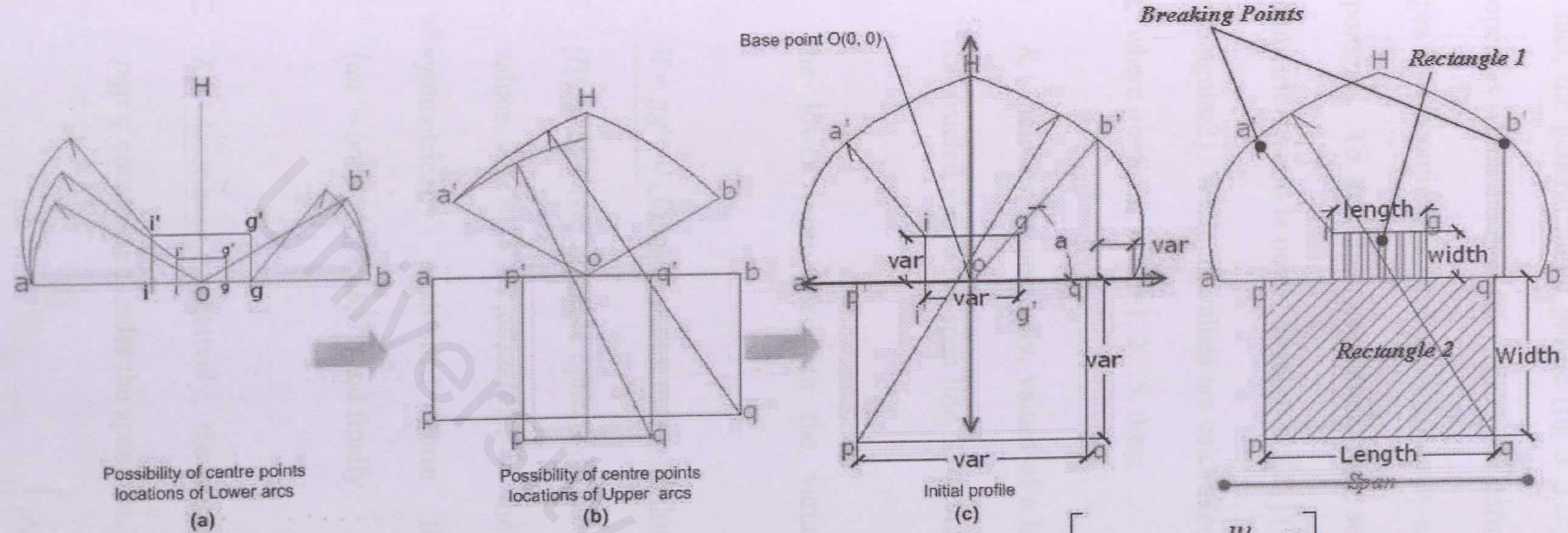
The framework of the four-centered profile can be developed as "a general initial shape" of the dome context. It is defined to provide the flexibility in its shape (or small arcs' curvatures) through application of the following essential definitions (fig 3. 12):

1. *The lower arcs*: are the loci of the points whose centers are located on the two vertices of the rectangle $ii'gg'$ constructed above the span line. Values of its lengths and widths are gained based on the exact proportions of the span: $\frac{m_i}{n_i}s$, (fig 3. 12a);

2. *The upper arcs*: are the loci of the points whose centers are always set on the two vertices of the rectangle $pp'qq'$ constructed under the span line. Values of its lengths and widths are obtained based on the fractions of the span $\frac{m'_i}{n'_i}s$ (fig 3.12b); and finally

3. *The Breaking Points*: are the couple of points a' and b' used for changing the profile curvatures through two considered options; firstly, it can occur by crossing the perpendicular lines $a''a'$ and $b''b'$ from the points a'' and b'' which are marked

from the end points of the span line based on the fraction of span $\frac{m''}{n''}\boldsymbol{s}$. Secondly, the points a' and b' are gained from the certain values of the springing angles: $\alpha = 25', 30', 60 and 45'$.



✓**Parametric system for presetting Geometrical Indications:**

$$\{[R_1], (B), [R_2]\} = \{\text{Rectangle 1, Breaking Points, Rectangle 2}\}$$

Where O (0, 0), ***ab*=Span**, i= 1, 2, …5,

$$R_1 = \begin{bmatrix} ig = i'g' = \frac{m_1}{n_1} ab \\ ii' = gg' = \frac{m_2}{n_2} ab \end{bmatrix} \begin{matrix} \textit{(Length)} \\ \textit{(Width)} \end{matrix}$$

$$(B) = \angle O = 25', 30', 60' \; and \; 45'$$

or $(aa' = bb' = m_3 / n_3 ab, 0)$

$$R_2 = \begin{bmatrix} p'q' = pq = \frac{m_4}{n_4} ab \\ qq' = pp' = \frac{m_5}{n_5} ab \end{bmatrix} \begin{matrix} \textit{(Length)} \\ \textit{(Width)} \end{matrix}$$

Figure 3. 12: Illustration on the development of geometrical parameters of a four-centered profile and its parametric system.

In fact, the general initial profile (fig 3. 12c) contains the whole essential geometric properties which are necessary; firstly, in definition of the geometric prototypes of both types of discontinuous double-shell domes and secondly in derivation of their exact typologies. To facilitate presenting and setting of its geometrical indications, a parametric system is newly developed $\{[R_1],(B),[R_2]\}$= {Rectangular1, Breaking point, Rectangular2}. While all values are calculated from the middle point of the span, O (0, 0), where *ab*=Span, and i=1, 2…5, then:

- R_1: includes, respectively, values of a length and a width of the rectangle $ii'gg'$ constructed above the span line. Two vertices of this rectangle are center points of the lower part arcs with the variable values as $\begin{bmatrix} ig = i'g' = \frac{m_1}{n_1}ab \\ ii' = gg' = \frac{m_2}{n_2}ab \end{bmatrix}$. When $ii' = gg' = 0$, then the centre points are located on the span line.

- *(B):* shows two possible options of the breaking points either as the exact angular values $\angle O = 25', 30', 60 and 45'$, or the coordinates values of points which are symmetrically positioned form the end points of span line as $(aa'' = bb'' = m_3/n_3 ab, 0)$; and finally

- R_2: describes, respectively, the values of a length and a width of rectangle $pqp'q'$ constructed under the span line. Two vertices of this rectangle are the centre points of the upper arcs as follows: $\begin{bmatrix} p'q' = pq = \frac{m_4}{n_4}ab \\ qq' = pp' = \frac{m_5}{n_5}ab \end{bmatrix}$

Note that the string "var", which means 'variance' in the drawings, is a specific dimension or distance for having varied parameter on the specific direction. This function helps in the flexibility of the analysis and in defining the rules for generating common prototypes for the given typologies' profiles. The given lengths in this system should be divided by two for obtaining the vertices i, g, p, and q of the proposed rectangles. In fact, the obtained vertices are symmetrically calculated and positioned on both sides of the vertical axis. This parameter system is essentially developed according to the Author contribution and dose not relies on the *al-Kashi* geometry.

i. The developed geometrical method for analyzing the pointed discontinuous double-shell domes

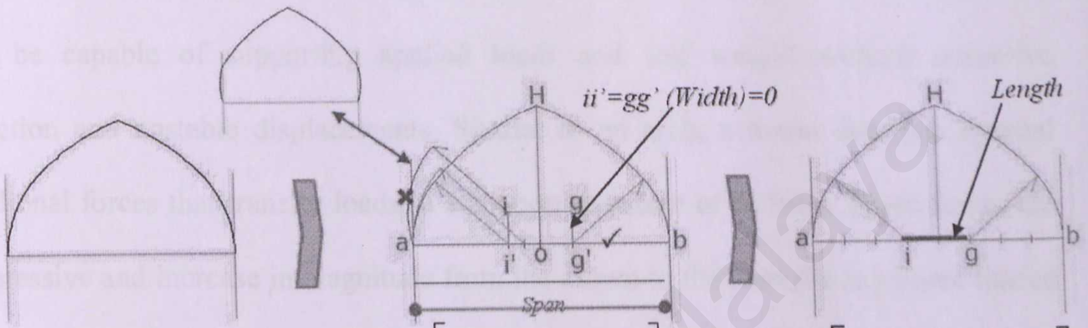
According to the historical literature[6], the discontinuous double-shell domes typologically are divided into three main subdivision types: conical, pointed, and bulbous. Except for the conical type, both pointed and bulbous types have the curvature profiles' characteristic.

Because of this, in the first step, a comprehensive geometrical method was primarily developed based on the new geometrical indications in such a way that they entirely covered both the bulbous and pointed typologies as elaborated in the previous sections.

Then, this developed four-centered initial profile has the potential of flexibility to remodel based on the pointed profile geometric properties in the second step that would be extensively elaborated in the approach section, in the next chapter[7]. In fact, this developed profile has been reconfigured again for examining the pointed discontinuous double-shell domes as follows (fig. 3. 13):

[6] Refer to sub-chapter 2.5.4 on Dome's Top: shell(s) for more information.
[7] Refer to page 175 on approach for geometrical survey.

- The lower arcs are the loci of the points whose centers are located on the span line. When the width of the rectangle $ii'gg'$ constructed above the span line equals 0, $ii' = gg' = 0$. On the other hand, two vertices of this rectangle are center points of the lower part arcs with the possible variable values as $\begin{bmatrix} ig = i'g' = \frac{m_1}{n_1} ab \\ 0 \end{bmatrix}$.



$$R_1 = \begin{bmatrix} ig = i'g' = \frac{m_1}{n_1} ab & \text{(Length)} \\ ii' = gg' = \frac{m_2}{n_2} ab & \text{(Width)} \end{bmatrix} = \begin{bmatrix} ig = i'g' = \frac{m_1}{n_1} ab \\ 0 \end{bmatrix}$$

Figure 3. 13: Illustration of derivation of the pointed geometric prototype and its formulation.

- The upper arcs are the loci of the points whose centers are always set on the two vertices of the rectangle constructed under the span line; and
- Breaking points: are the couple of points a' and b' used for changing the profile curvatures that are obtained from the values of the springing angles: $\alpha = 25', 30', 60 and 45'$.

3.3.4 An Introduction to Equilibrium Approach

The structural form of domes can simply be defined as the geometrical configuration of the space involved by the structure. However, within a similar external visible geometry, different structural actions could be responded by structure under the same kind of loads. Various capacities of different materials, internal detailing of cross-sections, the manner and sequence of construction and the dimensions of the dome can cause different structural actions in domes with similar overall geometry of the domical structures. Therefore, the geometrical configuration is only one aspect of the structural form of a dome (Unay, 2001).

Dome structures must provide strength, stiffness, and stability (Heyman, 1995). They must be capable of supporting applied loads and self weight without excessive deflection and unstable displacements. Similar to an arch, a dome develops internal meridional forces that transfer loads to a support structure at its base. These forces are compressive and increase in magnitude from the crown to the base for any dome loaded axis symmetrically by self weight (Wanda, 2002; fig. 3. 14).

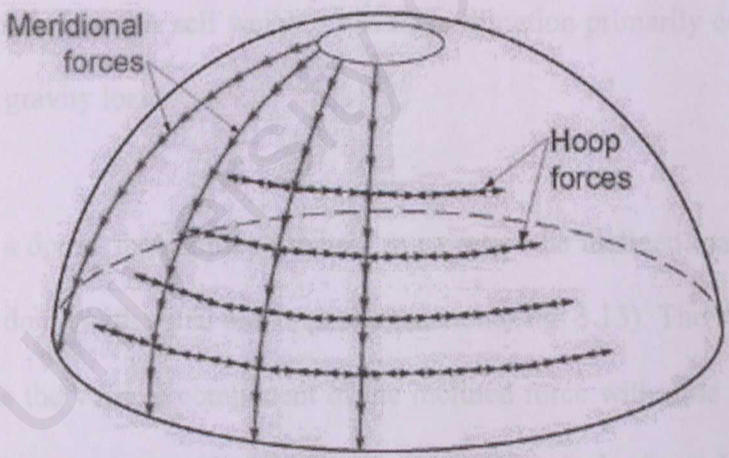


Figure 3. 14: Illustration of developing internal meridional forces and hoop forces throughout the semi-circular shell (Wanda, 2002).

Unlike an arch, a dome can resist out-of-plane bending of the meridians by developing internal hoop forces that act in the latitudinal direction as parallel rings. Hoop forces allow ring-by-ring construction of a dome without centering, an unfeasible task for an arch (Wanda, 2002). As a result, though an arch is unstable without its keystone, a dome with an oculus is perfectly stable, as evidenced by the "incomplete" domes around the world, such as the Pantheon in Rome or *Oljeitu* mausoleum in Iran (Wanda, 2002).

In fact, the problem was only to design domical structures supporting mainly their own weight when the governing criterion is strength. This is, indeed, one of the three fundamental structural criteria: strength, deformation and stability (Huera, 2001). A dome should resist its loads without the breaking of any of its members. It also should not present unduly large deformations.

Finally, the domical elements and the structure as a whole should be stable. In fact, it is a pile of bricks with mortar, disposed in such a way that they are in equilibrium under the force of gravity. Besides, it is a fact that the building maintains its form throughout the years (Huerta, 2001). Because of this, for traditional masonry domes, the predominant applied load is self weight; thus this estimation primarily considers domes loaded only by gravity loads.

At the base of a dome, the support structure must resist the inclined loads from the top element of the dome with equal and opposite reactions (fig. 3.15). The support structure typically resists the vertical component of the inclined force with ease (Wanda, 2002). However, the dome and support structure must also resist the horizontal component, the outward thrust, particularly near the base of the dome where total thrust is greatest. External means of resistance may be employed, such as massive support structure walls, as used in the Roman Pantheon, or a metal tension ring around the dome's base (Wanda, 2002).

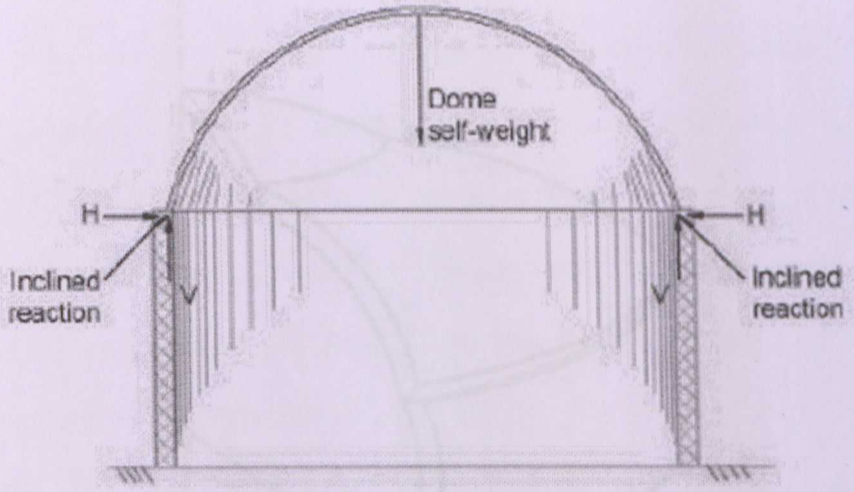


Figure 3.15: The support structure must resist applied and gravity loads with equal and opposite reactions (Wanda, 2002).

Local or comprehensive failure of domes may result from the masonry's inability to resist tensile or bending forces that develop due to unanticipated loads on the dome. A typical failure or collapse mechanism consists of: first, the formation of radial cracks along its meridians that divide the dome into lunes, or pie-shaped arches (fig. 3.16) (Wanda, 2002).

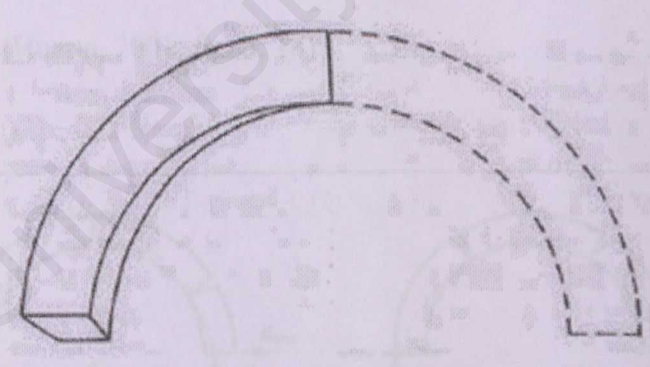


Figure 3.16: The dome may be considered as a radial series of lunes that comprise the dome (from Huerta, 2006).

Then, two hinge circles form in the dome mid-section, with a third hinge circle forming at or near the base. The cap of the dome will fall straight down, while the base of the lunes, as defined by the radial cracks, will rotate outward (Wanda, 2002; fig. 3. 17).

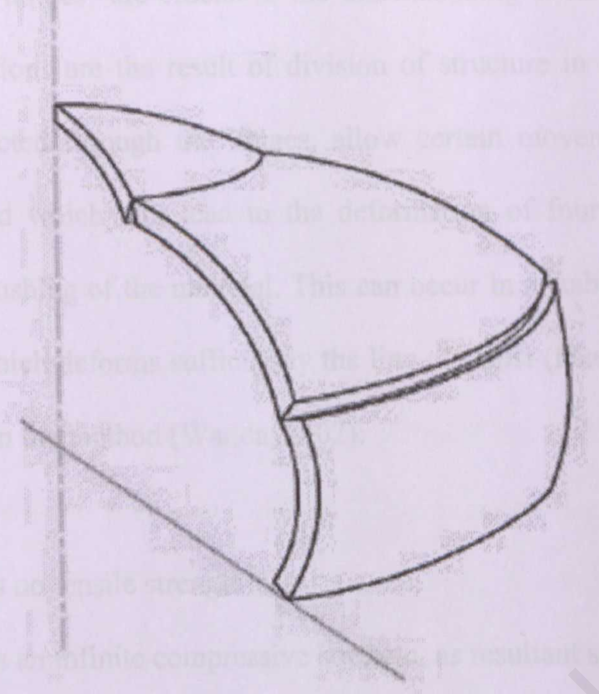


Figure 3.17: Typical collapse mechanism for a dome (Wanda, 2002).

For the analysis of masonry structures whose failure is more due to cracks opening than to material crushing, the Heyman approach is a simple and satisfactory method. In this approach, plastic analysis is used, in which the geometry of the way an arch might collapse is studied (Huerta, 2001; fig. 3. 18).

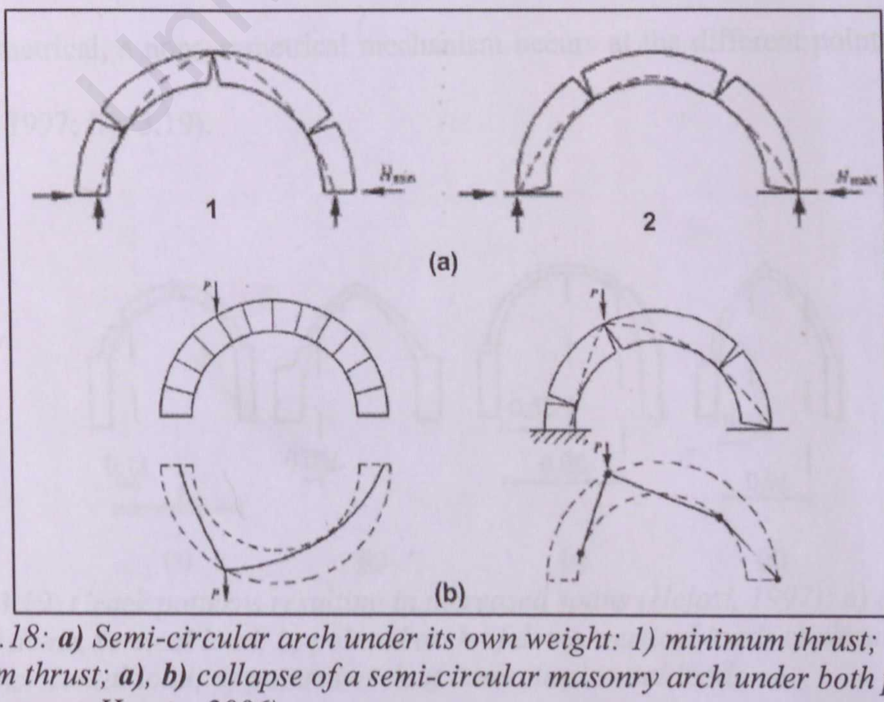


*Figure 3.18: **a)** Semi-circular arch under its own weight: 1) minimum thrust; 2) Maximum thrust; **a), b)** collapse of a semi-circular masonry arch under both point loads (Sources: Huerta, 2006)*

These concepts of "hinges" are crucial to the understanding of masonry structures. In particular, deformations are the result of division of structure in a certain number of parts which, connected through the hinges, allow certain movements. Therefore, an increase of the load which will lead to the deformation of four hinges will lead to collapse without crushing of the material. This can occur in a stable arch or dome with addition of load, which deforms sufficiently the line of thrust (Huerta, 2001). There are three assumptions in the method (Wanda, 2002):

1- Masonry has no tensile strength

2- Masonry has an infinite compressive strength, as resultant stresses are low

3- Sliding failure cannot occur

Since the material used in construction has no tensile strength, small displacements of the abutments cause hinging cracks along and near to the crest of the dome. For a symmetric dome structure, which is symmetrically loaded, a symmetric mechanism occurs. This symmetrical failure mechanism is formed in four hinges in the case of a pointed arch (Hejazi, 1997). If the geometry of the arch or dome loading is nonsymmetrical, a nonsymmetrical mechanism occurs at the different points of hinges (Hejazi, 1997; fig. 3.19).

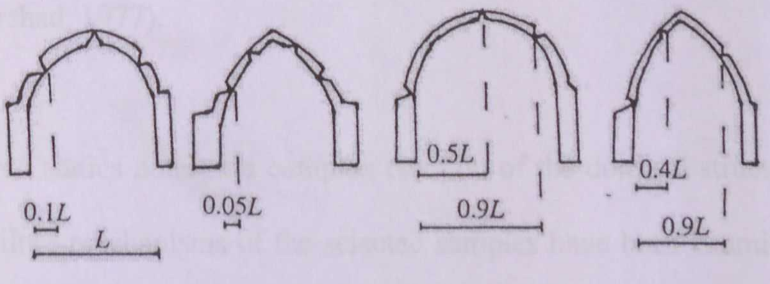


Figure3.19: Crack patterns resulting in increased spans (Hejazi, 1997): ***a)*** *circular arch of dome, vertical load;* ***b)*** *pointed arch of dome, vertical load;* ***c)*** *circular arch of dome, horizontal load;* ***d)*** *pointed arch of dome, horizontal load.*

From the engineering viewpoint, the theoretical results present a fairly good approximation of the internal force field in the middle part, that is, the major part of the dome. The membrane field of internal forces in the shell is disturbed and is modified by the bending field, the latter being a mechanism needed for equilibrium of the shell and its proper deformation (Farshad, 1977).

In fact, the bending field diminishes in magnitude as we move away from the kinked region whilst the internal stress and certain fields increase in regions of the lower boundary. The tensile force field which may develop in the shell is partly due to the membrane, and partly due to the bending action of the shell (Farshad, 1977).

In the cases of double-shell domes, when the upper edge of the dome is connected to another shell; the latter shell obviously has no tensile region either. In fact, the discontinuity in the slope at the top of the domical shell which is the characteristic feature of the pointed discontinuous double-shell dome entails certain structural implications (Farshad, 1977). The abutment of shell with lower part must supply/resist a certain value of forces and transfer it to the main load bearing items. As a result, the thicker part of the shell, which certainly is its lower part, was probably built as a non-flexible strap for receiving the magnitude value of forces. Technically, the tension had to be suppressed either by the choice of shell height and size, or the shape and thickness of the shell (Farshad, 1977).

Based on derived statics notes and complex reaction of the domical structure, the only symmetrical failure mechanisms of the selected samples have been examined by using the Finite Element Analysis (FEA) as a common tool to analyze failure mechanism of any kind of structures. In terms of developing discussion about the relation between architectural and structural concepts, the models' results have been compared with their relevant geometrical design and configuration of the internal stiffeners in Chapter Five.

i. Application of the Finite Element Analysis (FEA)

Monumental architectures and the design conceptions on which they are based inevitably have structure at their very core. As a result, the form and the structure of many great monumental works of architecture are closely interwoven. They are so integrated that any attempt to study form or style in such buildings must be based on an intermediate understanding of the structural principles at work (Morris *et al.*, 1995).

Almost in all engineering fields, Finite Element Analysis (FEA) plays an important role in researches and design. The graphical outputs of FEA contribute to the ability of interpretation of result and also provide great intuition even for non-technically educated colleagues. Therefore, architects, architectural historians, restoration specialists and archaeologists can also be involved in analysis of structural problems of historical buildings (Unay, 2001; fig. 3.20).

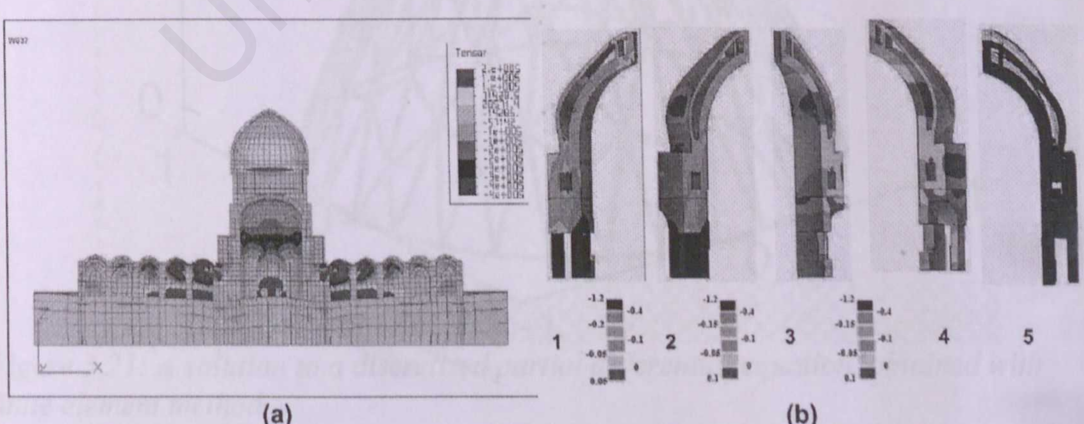


*Figure 3.20: Two samples of historic domes modeling analysis for the safety degree of dome (Croci, 2001): **a)** Tilla Kari mosque-Uzbekistan **b)** Basilica of S. Maria of Carignano, Italy.*

The basis of the Finite Method is the representation of a structure as a finite number of lines and two-dimensional subdivisions. These subdivisions are called finite elements. These elements are interconnected at joints called nodes. The external loading is transformed into equivalent forces applied to nodes and the behavior of the elements is prescribed by relating their response to that of the nodes (Morris *et al.*,1995).

Structural analysis of historical structures is mostly performed using Finite Element Analysis. The analysis begins by generating a finite element model of the entire structure or structural element. This is called the discretization of the structure (Morris *et al.*, 1995). During the discretization, the structure is divided into elements that are critical in establishing the accuracy of the solution (fig. 3.21). The choice of the number, size and type of elements is a matter of judgment. All these modeling procedures, considering the geometry of the structure, joint restraints and the loading are called the analytical model of the structural analysis at all (Morris *et al.*, 1995).

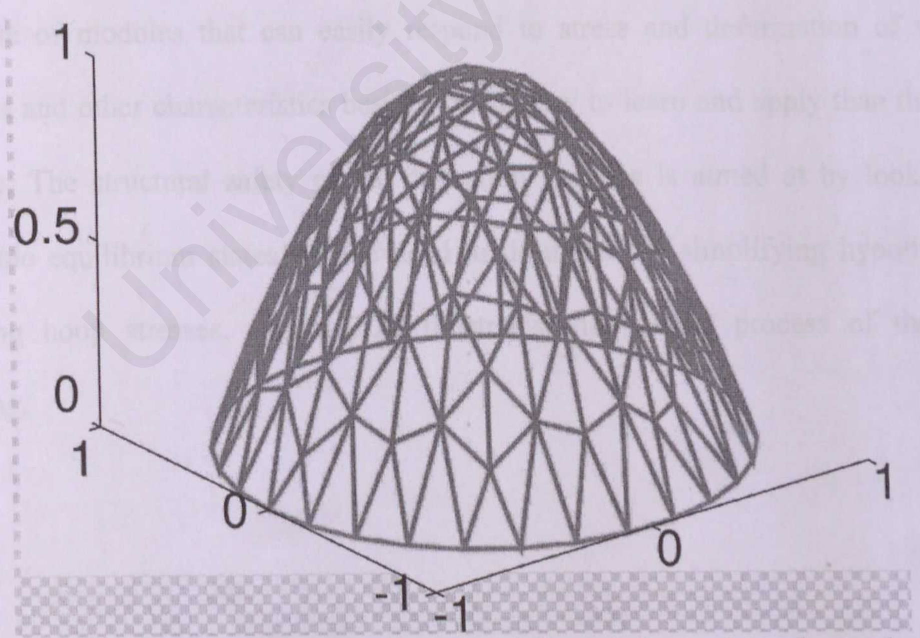


Figure 3.21: A solution to a discretized partial differential equation, obtained with finite element method.

The purpose of analytical modeling is to try to represent the actual behavior of a structural component or entire structure in mathematical terms. The actual behavior of the structure is usually highly complex and many simplifications have to be made in order to model it. To achieve a refined model, material behavior has to be simulated properly, supports and connection of elements have to be modeled and the loading has to be defined (Croci, 1998; Morris *et al*., 1995).

3.3.5 Methods of Analysis and Assumptions

The approximate structural behavior of the common prototypes, which are deduced from the analysis of cases studies are analyzed under symmetrical loading condition. By using a finite element method for the structural analysis, problems of fracture or crack boundaries of each generic sample are examined.

The finite elements programs including engineering software such as ANSYS, ADINA and ABAQUS, are widely used for structural analysis. Briefly, ABAQUS (Version 6-1) is a suite of modules that can easily respond to stress and deformation of various materials and other characteristics besides being easy to learn and apply than the other software. The structural safety of the deduction samples is aimed at by looking for admissible equilibrium states for the dead loads under the simplifying hypothesis of vanishing hoop stresses. Figure 3.22 illustrates the general process of the FEM modeling.

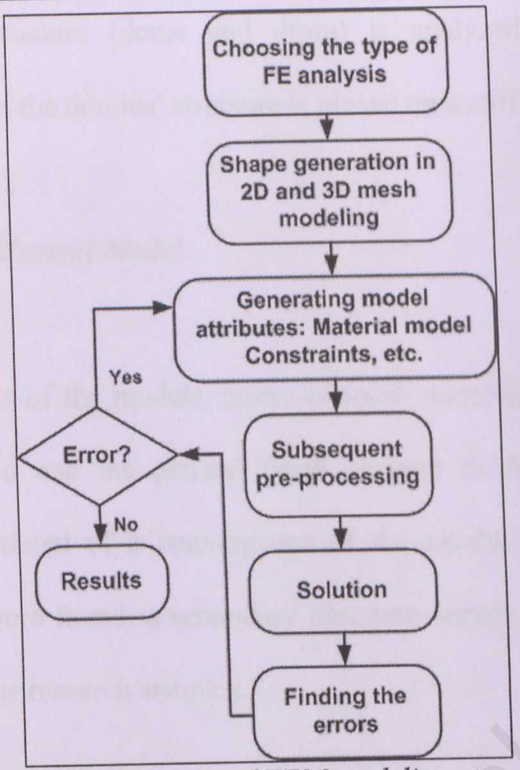


Figure 3.22: Illustration of flow chart of FEM modeling steps (Morris et al., 1995).

In the finite element analysis of these domes, the following assumptions have been made (Hejazi, 2006):

1. Because of symmetrical form of dome, half section is modeled;
2. The material properties are as shown in Table 3.2;

Table 3.2: Illustration of material properties of masonry brick domes (Hejazi, 2003).

Modulus of elasticity E N/mm^2	Poisson ratio υ	Weight density γ kN/m^3	Allowable compressive stress f_c N/mm^2	Allowable tensile stress f_t N/mm^2	Allowable shear stress f_v N/mm^2	Allowable bearing stress f_b N/mm^2
7.358×10^3	0.1	18.541	0.7	0.2	0.1	0.7

3. The masonry materials have linear elastic behavior;
4. Materials are isotropic;
5. Since the lower part (drum) of the structure (composed of dome and drum) is very stiff, the connection of the base of the drum to its substructures is such that all displacements and rotations of the base are vanished, except the rotation around the circumference of the base parallel circle; and finally

6. The domical structure (dome and drum) is analyzed independent of the substructure, as if the domical structure is placed on a stiff support.

i. Validation of Finite Element Model

After several executions of the models, errors of mesh material model, and boundary conditions were revised and the general finite element model was validated. The validation process consisted of a convergence of the results. During the validation process, when errors were found, a secondary literature survey was conducted to find out new ideas from other research samples.

In order to verify the mesh generated by the ABAQUS programs and make convergence analysis, the 3D models have been transferred from the Auto CAD to this software. Four general shapes, which are derived from the twelve case studies, have been selected for final modeling by the Finite Element under gravity. Figure 3.23 illustrates the selected domical forms in AutoCAD: 2D and 3D drawings as well as the transferred CAD model into ABAQUS software.

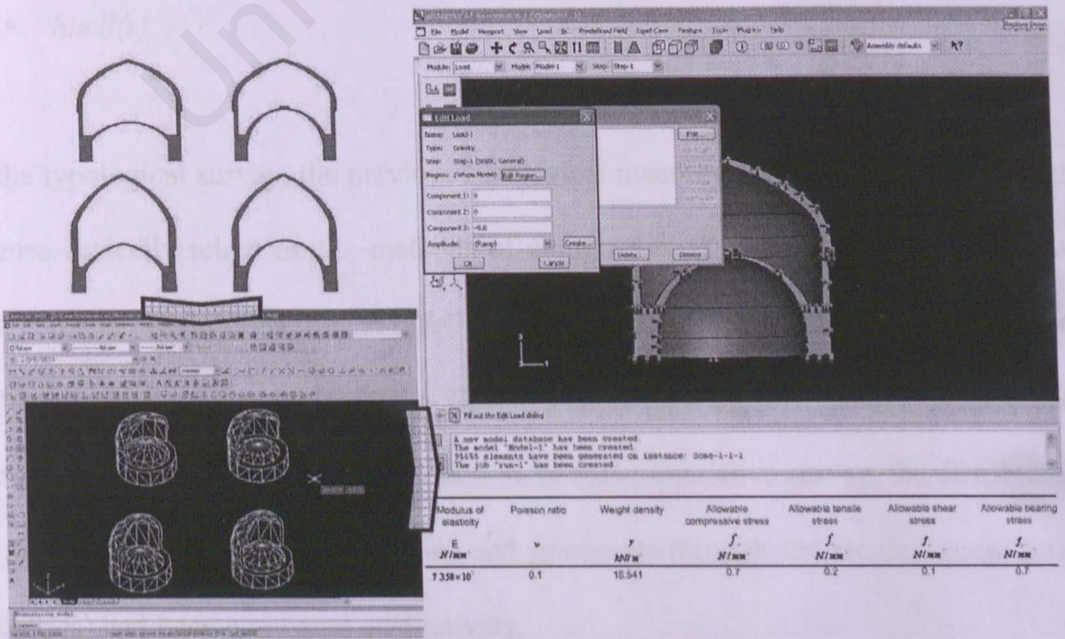


Figure 3.23: Illustration of transferring a domical 3D-CAD model from AutoCAD into ABAQUS software.

3.4 Summary and Conclusion

Despite the several existing studies on the Islamic domes and relative meanings, much is still uncertain and vague, especially with the respect to understanding typologies, morphological aspects, and the common patterns of "formal architectural language" of the Eastern Domes.

For filling these gaps, the approaches were structured based on the comparative survey, morphological survey, and typological survey using the specific tables. These tables' contexts were organized based on the qualitative view of concern called, "*visual language*" of the Eastern Domes. The visual language is dedicated to the common vocabularies (or morphological features) and grammars (typological configurations) of Islamic domes. From the morphological point of view, these generic vocabularies can be listed as follow:

- *Supporting system as load bearing system or barrel vaults*
- *Transition tier*
- *Drum*
- *Shell(s)*

In the typological survey, the previous typological meanings (grammars) of the Eastern Domes basically relied on the methods of compositional of shells. In this sense, two new broader definitions of "*simple*" and "*compound*" grammars Were developed architecturally and terminologically. They indicated how those vocabularies have been composed together in a dome configuration. In the comparative survey, the distributions of the various shapes of vocabularies and grammars through the studied zones (eight countries) had been compared qualitatively.

Despite several existing studies about the Islamic domes and their relative meanings, ***the pointed discontinuous double-shell domes still do not have completely well-known morphological features, typological characteristics, geometrical contexts, and even associated terminologies.***

In terms of filling these gaps, multifold approaches have been organized including, morphological survey, typological survey, geometrical survey, and structural survey in order to estimate constitutions of the pointed discontinuous double-shell domes and to specify their common architectural prototypes.

Historically, the Islamic mathematicians played a significant role in development of Eastern Domes especially in the early medieval Islamic era. In fact, a striking feature of the Islamic mathematics, in contrast to Greek mathematics, is the close relationship between theory and practice which is called 'the mathematics of practitioners'. The main efforts aimed to define and formulate 'an exact geometric approach' than determining the certain proportions, rather than plain analyzing the domes.

The primary textual signs of the assistance of mathematicians may see in the Ismail Samanid Mausoleum. Forms of this mausoleum were entirely turned by the devised geometry of al-Khorezmi, al-Fargani, and Ibn-Sina. The long absence of developments from ca. 1200 until ca. 1400 was the result of the genocide of scientists by several invasions of the Mughals and their successor, Timur. Soon after, the contribution of mathematicians continued until Ghiyath al-Din Jamshid Mas'ud Kashani (*al-Kashi*) who ranks among the greatest mathematicians and astronomers in the Islamic world in the medieval era.

By far his extensive book is *Key of Arithmetic* (Book IV), on "Measurements" where the last chapter, "measuring structures and buildings", was written for practical purposes by using geometry as the tool for his calculations.

His five methods for drawing the "profile" of an arch and dome from the *al-Kashi Key of Arithmetic* are listed as follows:

- The first and second approaches addressed the designing of a three-centered profile according to the divisions of the circle respectively into six parts and eight parts (approaches 1 and 2);
- The third approach illustrated a four-centered arch which was drawn based on the construction of a rectangle under the span line and division of the span line into eight parts (approach 3); and
- The fourth and fifth methods depicted the geometry of two-centered arches based on either the division of the span line or the formation of rectangle under the span line (approaches 4 and 5).

In the geometrical survey, in order to propose a framework in defining a formal geometrical language, the external shell, which is considered as the typical feature of such a dome and embracing the employed practice geometry, is the object of this investigation. The key in understanding the external geometric composition is mainly dealt with by studying a cross-section of the external shell when its thickness is diminished. This so called, 'profile', forms the basis of the domical geometric design. Its fundamental properties consist of the '*Span*' and the '*Rise*'.

The *al-Kashi* geometric approaches were used for designing common shapes of profiles of arches, vaults, and domes at that time, and hardly covered the majority of geometrical compositions of the Islamic domes with their different attributes at various periods. However, the *al-Kashi* four-centered profile has the potential to be enhanced extensively through the expansion of the three geometrical parameters, including the locations of the first and second arcs, the locations of the third and forth arcs, and the positions of the breaking points.

The framework of the four-centered profile as the initial shape of the domical context can be developed in order to provide the flexibility in the profile shape for analyzing both pointed and bulbous discontinuous double-shell domes through the application of the new three essential definitions:

- The lower arcs are the loci of the points whose centers are located in the rectangle $ii'gg'$ constructed above the span line in which its lengths and widths are based on the exact proportions of the span: $\frac{m_i}{n_i}s$;
- The upper arcs are the loci of the points whose centers are always set on the two vertices of the rectangle $pp'qq'$ constructed under the span line and its lengths and widths of which are based on the fractions of the span $\frac{m'_i}{n_i'}s$; and
- Breaking points: are the couple of points a' and b' used for changing the profile curvatures through two options; firstly, it can occur by crossing the perpendicular lines $a''a'$ and $b''b'$ from the points a'' and b'' which are marked based on the fraction of span $\frac{m''}{n''}s$. Secondly, the points a' and b' are obtained from the values of the springing angles: $\alpha = 25', 30', 60 and 45'$.

Note that the discontinuous double-shell domes typologically are divided into three main subdivision types: conical, pointed, and bulbous. Except for the conical type, both pointed and bulbous types have the curvature profile characteristics.

In the first step, using *al-Kashi* geometrical essences, the above comprehensive geometrical method was primarily developed based on the new geometrical indications in such a way that they entirely covered both the bulbous and pointed typologies.

Then, this developed four-centered initial profile has the potential of flexibility to remodel based on the pointed profile geometric properties in the second step which would be extensively elaborated in the approach section, in the next chapter. In fact, this developed profile has been reconfigured again for examining the pointed discontinuous double-shell domes as major type of discontinuous double-shell domes as follows:

- The lower arcs are the loci of the points whose centers are located on the span line;
- The upper arcs are the loci of the points whose centers are always set on the two vertices of the rectangle constructed under the span line; and finally
- Breaking points: are the couple of points a' and b' used for changing the profile curvatures that are obtained from the values of the springing angles: $\alpha = 25', 30', 60 and 45'$.

On the other view, the developed comprehensive initial profile was reorganized explicitly for derivation process of the geometrical concepts of the pointed discontinuous double-shell domes. Based on the *al-Kashi* geometrical approach, this theoretical framework was geometrically developed to exhibit the essences of geometric prototype of the pointed discontinuous double-shell domes. By using the developed initial profile with the new geometrical parameters, architectural and geometrical languages for the pointed discontinuous double-shell domes are specified.

To facilitate the presentation of the geometric variables of this initial profile depending on the new parameters, a parametric system, which consists of all parameters of the initial profile with base from O (0, 0) as middle point of the span, is proposed and developed as follows: $\{[R_1],(B),[R_2]\}$= {Rectangular1, Breaking point, Rectangular2}, ab=Span, and i=1, 2…5, where:

- R_1: includes values of length and width of the rectangle $ii'gg'$ constructed above the span line. Two vertices of this rectangle are centre points of the lower part arcs with the possible variable values as $\begin{bmatrix} ig = i'g' = \frac{m_1}{n_1}ab \\ ii' = gg' = \frac{m_2}{n_2}ab \end{bmatrix}$.
- ***<u>When ii'=gg'=0, then the center points are located on the span line which used for analyzing the pointed discontinuous double-shell case studies</u>***(These would be elaborated in the next chapter).
- *(B):* shows two various options of the breaking points either as the exact angular values $\angle O = 25', 30', and 45'$, or the coordinates values of points which are symmetrically positioned on the span line as $(aa'' = bb'' = m_3 / n_3 ab, 0)$; and
- R_2: describes the values of length and width of rectangle $pqp'q'$ constructed under the span line. Two vertices of this rectangle are the centre points of the upper arcs as follows $\begin{bmatrix} p'q' = pq = \frac{m_4}{n_4}ab \\ qq' = pp' = \frac{m_5}{n_5}ab \end{bmatrix}$

In the structural survey, local or comprehensive failure of domes may typically result from the masonry's inability to resist tensile or bending forces that develop due to unanticipated loads on the dome. A typical failure or collapse mechanism consists of, firstly, the formation of radial cracks along its meridians that divide the dome into lunes, or pie-shaped arches. Secondly, two hinge circles form in the dome mid-section, with a third hinge circle formation at or near the base. The cap of the dome will fall straight down, while the base of the lunes, as defined by the radial cracks, will rotate outward.

In this regard, in order to understand the approximate boundaries of typical failures of the pointed discontinuous double-shell domes, a structural survey is needed by using the ABAQUS engineering software. On the other hand, by using this approach, the vulnerability of the pointed discontinuous double-shell domes has approximately been determined. These results can be utilized in any conservation interventions of such domes.

This chapter concluded with the presented methods which would in sequence be applied to the selected samples in the next Chapter (organized into two parts) to examine the common architectural and conceptual properties of both Eastern domes and the pointed discontinuous double-shell domes.

Chapter 4
Research Case Studies and Analysis

4.1. Introduction

In Chapter Three, the methods for analyzing samples were extensively introduced and elaborated. This chapter includes samples and their analysis based on those presented methods. By selecting these examples, Research aimed to answer three essential questions about the Islamic domes from the early Islamic era through the late Islamic era:

- What are the typical morphological features (the four generic vocabularies or forms) of the Islamic domes in the various boundaries of the Middle East and Central Asia?
- What are the typological aspects or compositional grammars of the Islamic domes in the different regions of the Middle East and Central Asia?
- How important are the distributions and emphases of these aspects of the Islamic domes throughout the Middle East and Central Asia?

Regarding the part one of Research, this chapter firstly traces methods of selections of domes located in Iran, Iraq, Turkey, Afghanistan, Pakistan, Turkmenistan, and Uzbekistan. In the step one, samples are respectively arranged in the provided Tables 4.1 and 4.2 according to their regional similarities. Each sample has comparatively been examined according to diversity of its general features which are supporting systems, transition tier, drum, and shell(s) and finally its organization traits. The examinations of fifty three samples contain their various names (if possible), location, client (if possible), style or period, date, building usage, and building type, according to morphological and typological surveys which are shown in Tables A. 1, A.2, A. 3, and A.4.

Then, common prototypes of these studied domes were listed as analogical shape-patterns and would extensively be discussed in Chapter Five. As a result of Part One of this research, the pointed discontinuous double-shell domes were highly discovered as a major aspect of Islamic domes in the Middle East and Central Asia.

Secondly, the Chapter establishes a list of twelve selected pointed discontinuous double-shell domes, chosen from fifty three samples located in four countries including Iran, Afghanistan, Uzbekistan, and Kazakhstan for greater detailed considerations. By selecting these examples of the pointed discontinuous double-shell domes, Research aimed to answer four essential questions about the pointed discontinuous double-shell domes from the medieval Islamic era through the late Islamic era:

- What are the morphological features of the pointed discontinuous double-shell domes in the Middle East and Central Asia as a main feature of the Islamic domes in the Middle East and Central Asia?
- What are the distinct typological aspects of the pointed discontinuous double-shell domes in the Middle East and Central Asia?
- What are the common geometrical prototypes of this type of the Eastern domes in the Middle East and Central Asia?
- Where are the vulnerable parts of such Eastern domes, structurally?

In addition, this chapter presents a brief historical background of these cases, their architectural characteristics, and explanation of their analysis steps. In meanwhile, by using the developed four-centered initial profile, the geometrical compositions of such domes have been analyzed and deduced.

In both parts, each dome was analyzed according to its plans, photographs, and, whenever possible, site visits to determine the relative levels of architectonic conceptual organizations[1]. The studied periods and selected cases are particular causes for the development of those domes that were never surpassed in other periods later on.

4.2 Part One: Selections of Zones and Samples

i. Selection of Zones

To determine the prevalence of the aforementioned generic forms and grammars according to regional orders, fifty three dome samples have been selected from the Middle East and Central Asian countries. In fact, based on the historical investigations in Chapter Two, countries have been selected in the first part of research which played the significant role in development of Eastern domes, since the early Islamic era (1000 A.D.) until the late Islamic era (1800 A.D.) (fig. 4.1); These countries are as follows: Turkey, Iran, Iraq, Afghanistan, Pakistan, Turkmenistan, Kazakhstan, and Uzbekistan. (fig 4.2).

[1] The whole documents and analysis have been carried out according to the Secondary data.

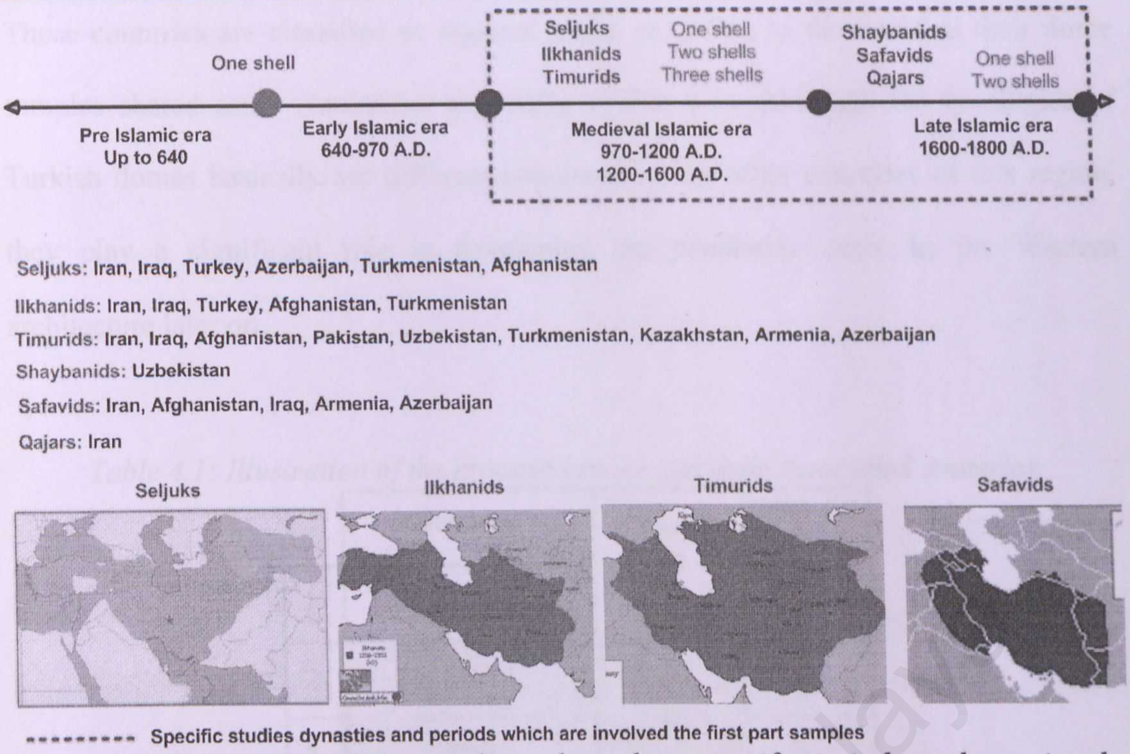


Figure 4.1: Illustrations of Eastern dome chronology, specific periods, and associated countries of the Middle East and Central Asia.

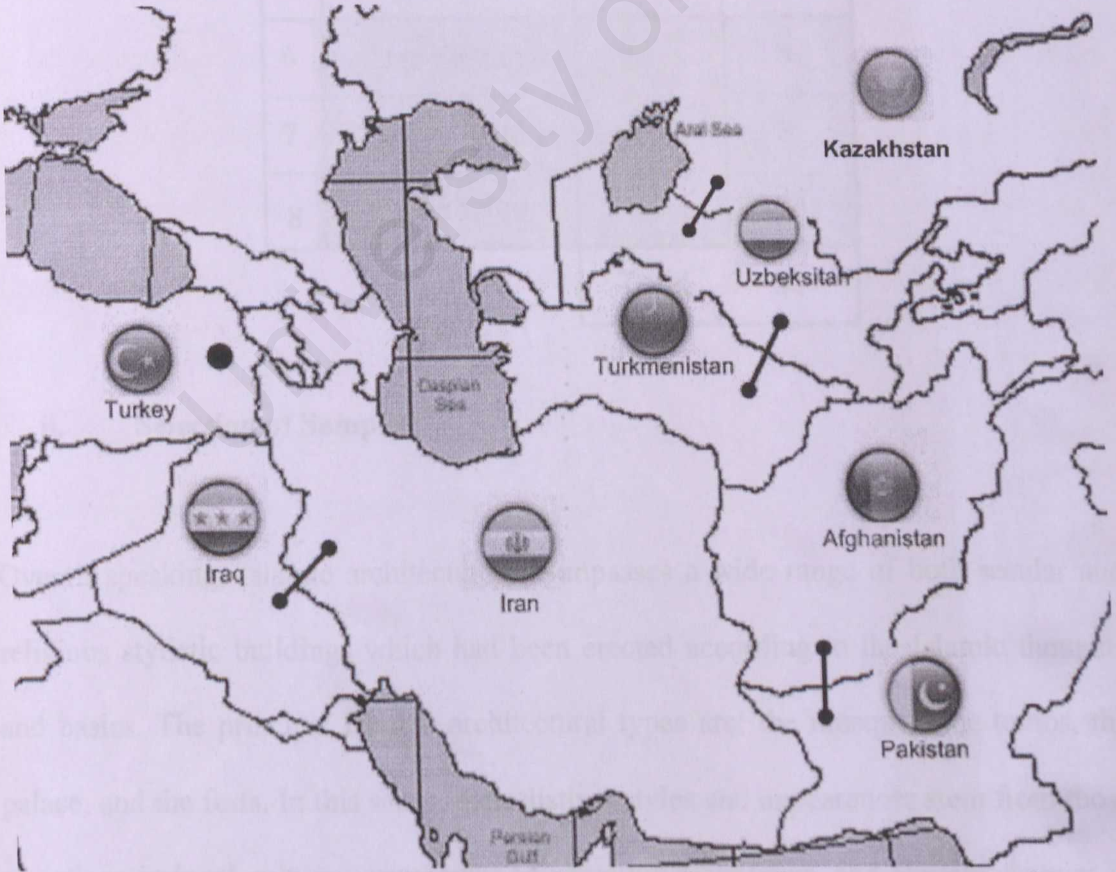


Figure 4.2: Illustration of the definitions of zones and considering countries in the Middle East and Central Asia.

Those countries are classified as regional zones according to the fact that their dome samples shared some similarities regionally (Table 4.1). Although the typologies of Turkish domes basically are different compared to the other countries of this region, they play a significant role in developing the *pendentive* style in the Western architecture later on.

Table 4.1: Illustration of the proposed zones and their associated countries.

	Countries	Zone	Number of samples
1	Turkey	I	11
2	Iran	II	12
3	Iraq		5
4	Afghanistan	III	6
5	Pakistan		7
6	Uzbekistan	IV	8
7	Turkmenistan		3
8	Kazakhstan		1
		Total	53

ii. Selection of Samples:

Overall speaking, Islamic architecture encompasses a wide range of both secular and religious stylistic buildings which had been erected according to the Islamic thoughts and basics. The principal Islamic architectural types are: the mosques, the tombs, the palace, and the forts. In this sense, their distinct styles and appearances stem from those variations in local cultures, vernacular construction techniques, and climate changes of Islamic lands. Both tombs and mosques are subjects of case studies of this Research.

-Tombs: despite the extreme prohibition against building of tomb structures, the earliest samples were erected by Abbasid Sunni rulers at Samarra in Iraq, after construction of the Dome of Rock. Soon after appearing the two Islamic branches of Sunni and Shiite, constructions of funerary buildings, topped with primary samples of domes, became a specific trend which was rather dogged by Shiite governors in Islamic architecture

-Mosques: represent the heart of Muslim religion and embrace two common types: with domes and without domes (earliest edifices). The dome, popular in Iran and majority of the Middle Eastern countries, mainly employed for the symbolic interpretations purposes. Nevertheless, it was adopted from pre-Islamic architecture in the mosque architecture since the Seljuk Empire.

In the selection of samples, main effort concentrated to choose those samples which have revealed the dome styles of those countries. Table 4.2 presents an overall view of fifty three samples whilst tables A-1, A-2, A-3, and A-4 in Appendix One contain their detailed analysis information as follows: brief historical and architectural backgrounds, evaluating the four generic vocabularies and finally their typological considerations. Each dome was comparatively analyzed according to its plans, photographs, and, whenever possible, site visits to determine the relative levels of architectonic conceptual organizations.

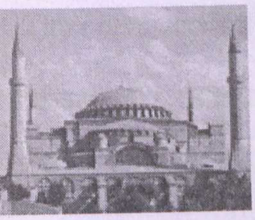
The comparative survey, as an essence of this part of Research, was carried out, not only to identify the dominant aspects of the Islamic domes in every region of the Middle East and Central Asia, but it specifies also the distributions of their vocabularies and grammars.

The results of this study indicate the existence of the definite visual languages, either as development compositional features or as simple appearance, possessing both vocabularies and grammars (morphology and typologies)[2]. The vocabulary basically deals with the distinct models of the four generic parts of the dome. In fact, it concerns about their architectural constitutions. The grammar, on the other hand, relates to various systems of organizing these parts into a coherent whole whether as a simple organization or a compound configuration.

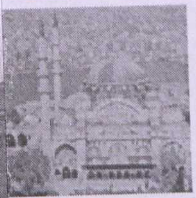
Some points have to be underlined. It seems that diversity of these visual languages mainly related to various ecological and cultural regions of the Middle East and Central Asia. Secondly, some parts of the vocabulary and grammar may still be general societal agreements, whereas other parts of the defined language are very regionally bound. An example of the regional grammar is the double-shell typology which is the dominant feature of domes in Uzbekistan despite the typical one shell composition of domes in Turkey. Another example of regional vocabulary is the use of the drum which received much emphasis in the Uzbekistan region, but it was rather undeveloped in the Iraq region.

Thirdly, the presented visual language is modes of architectural expressions as tools for analyzing the selected samples. Just as a dictionary and a handbook of the Islamic dome constitution do not guarantee a masterpiece of literature.

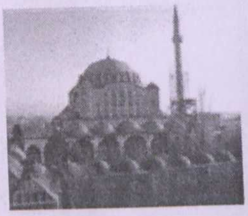
[2] Refer to Chapter One- Pages 14 , 15 and 26 for extensive elaborations.

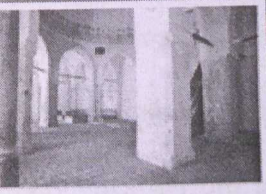

Hagia Sophia mosque
Turkey


2 Ruste


ymaniye mosque
Turkey


9 Bayezid II mosque
Turkey

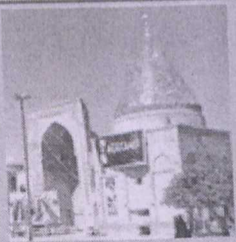

10 Mihrimah mosque
Turkey

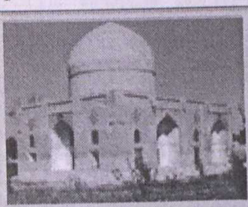

11 Great mosque
of Manisa
Turkey


1 Gre


Rida shrine
Iran


8 Amir Chaqmaq mosque
Iran


9 Bayazid Bistami shrine
Iran


10 Amin-edin Jebrail tomb
Iran


11 Nure


at mosque of
Nur al-Din
Iraq

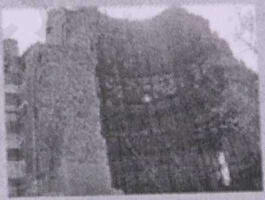

1 Abu Nasr Parsa
mausoleum
Afghanistan

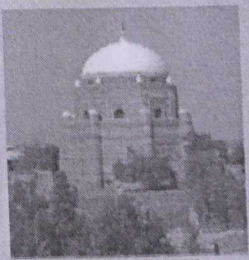

2 Kahsan mausoleum
Afghanistan

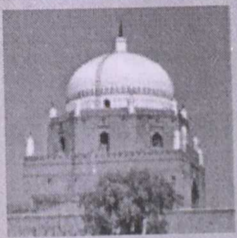

3 Gawhar shad
mausoleum
Afghanistan


4 Sh


Ul-Haleem tomb
Pakistan


4 Uch Sharif tomb
Pakistan


5 Shah Rukn-I Alam
tomb
Pakistan


6 Sheikh Zakariya
mausoleum
Pakistan


7 Su
Qat


Jahangir
mausoleum
Uzbekistan


7 Bibi Khanum
mosque
Uzbekistan


8 Shah-I Zindeh
mausoleum
Uzbekistan


1 Sultan Sanjar
mausoleum
Turkmenistan


2 Jama
Tu

The organized Table 4.3 included all evaluation information derived from the analysis of samples based on the comparative survey in every zone. The deduced issues are quantitatively organized and modeled in relative tables in the next Chapter.

Overall speaking, the domes in zone I (Turkey) show different architectonic concepts. The typical shape of their shell is one shell with saucer formation. While their supporting systems are huge and imposing in size, their compositional system and organization did not show any particular development. The square and/or hexagonal shapes with lateral vaults are the typical forms of the supporting systems in this realm. The typical recognized transition tier composed of *pendentives* as the main symbol of Byzantine architecture. Drums embrace many-sided shapes with medium scale of height (Table 4.3).

There likely seems neither sample of the double shells domes nor the pointed formations exist in this realm. On the other hand, these dome conceptualisms are completely in contrast with the other studied regions. The identified shell shape in this zone is either shallow saucer form or semi-circular shape.

In zone II including Iran and Iraq, the square shape of supporting system with bearing walls is the dominant feature of bodies of domes. The shells rested on *squinches* transition tier with the developed shape, especially in Iran. The double shell domes erected on the high circular drums are typical features of both territories. The only triple shells had also been recognized in Iran. The typical derived formations of shells are seen as follows: conical, pointed, and bulbous. The main grammars of dome assembled system were double-shell with compound and complex systems erected on high drums (Table 4. 3).

In zone III including Afghanistan and Pakistan, the domes showed various geometrical patterns and aspects. On the other hand, the typical shapes of domes in Afghanistan were the pointed discontinuous double-shell domes with the huge drum as well as compound grammar of organization whilst the typical shapes of Pakistani domes were the Mongol style (shallow semi-circular form) with both simple and compound configurations (Table 4.3). The supporting systems embrace into two different aspects: square with bearing walls and square with lateral vaults. Also, double and triple shells are dominant features of the domes in Afghanistan more than Pakistan. The identified external shell forms in this zone can be listed as follows: pointed and bulbous (mainly in Pakistan).

In zone IV including Uzbekistan and Turkmenistan, the majority of the domes are the pointed discontinuous double-shell domes with complexity in their *squinches* transition tier. The main organization grammar of these samples was compound with the high cylinder formation. The typical characteristic style of the zone IV domes are known with the high drums and imposing external shells stabilized by projecting brick ribs called by Jalal Yaghan (2003) as "gadrooned domes". Nevertheless, their external shells were appeared in both pointed and conical forms (Table 4.3).

Table 4.3: Inventory of the qualitative analysis of vocabularies and grammars of studied domes in four zones.

Dome typology

Shell

Zone I — Turkey

No.	Locale	Name	Supporting system: Cylindar	Supporting system: Square with bearing wall	Supporting system: Square with lateral vault	Supporting system: Other	Transition tier: Pendentive	Transition tier: Squinch	Drum: Cylinder	Drum: Many-Sided	Shell: One	Shell: Two	Shell: Three	Dome Typology: Simple: With drum	Dome Typology: Simple: Without drum	Dome Typology: Compound: With drum	Dome Typology: Compound: Without drum	Century of construction A.D.
10		Gawhar Shad mausoleum		●				●	●				●			●		15
11		Abu'l Qasim Shrine		●				●	●			● ?				●		15
12		Abu Mansur mausoleum						●			●				●			14
13		Hazrat Ali shrine complex		●				●	●			●				●		18

Zone IV — Uzbekistan & Turkmenistan

No.	Locale	Name	Supporting System: Cylindar	Supporting System: Square with bearing wall	Supporting System: Square with lateral vault	Supporting System: Other	Transition tier: Pendentive	Transition tier: Squinch	Drum: Cylinder	Drum: Many-Sided	Shell: One	Shell: Two	Shell: Three	Dome Typology or Generic form Grammar: Simple: With drum	Simple: Without drum	Compound: With drum	Compound: Without drum	Century of construction A.D.
1	Uzbekistan	Kalyan madrasah		●				●	●			●				●		15-16
2		Mir-i Arab madrasah		●				●	●			●				●		18
3		Talla kari madrasah		●				●	●			●				●		17
4		Bibi Khanum mosque		●				●	●			●				●		14-15
5		Amir Timur mausoleum		●				●	●			●				●		15
6		Jahangir mausoleum		●				●	●			● A		●				15
7		Samanid mausoleum		●				●			●				●			10
8		Shah i-Zindeh mausoleum		●				●	●			●				●		11-15
9	Turkmenistan	Sultan Sanjar tomb		●				●	●			●				●		12
10		Turabek Khanym mausoleum			●			●	●				● A			●		11-15
11		Jamal al-din Shrine		●				●	●			● A				●		15

Keys: ? Insufficient information A Conical shell

4.3 Part Two: Selection of Samples and Countries

The analysis of the Islamic Eastern samples indicates that the pointed discontinuous double-shell domes are typical configuration of Islamic domes between those studied countries, despite the regional arrangements of the other type of Islamic domes such as conical and bulbous[3].Countries selected for the second part of Research are: Iran, Afghanistan, Uzbekistan, and Kazakhstan which include the majority of such domes.

The formal prototypes and theories were created using a corpus of twelve case studies which were built in those regions, from 1067 A.D. (appearing primary sample of the pointed discontinuous double-shell domes) through 1600 A.D (the end of medieval Islamic era) (*see* fig. 4.3). The main building usages of those monuments are as tombs (most of primary samples) mausoleums, mosques, and *madrassa*[4].

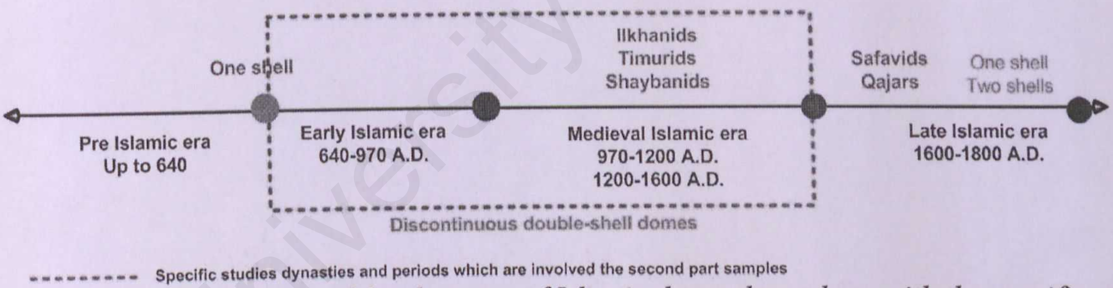


Figure 4. 3: Illustrations of development of Islamic dome chronology with the specific selected periods for the second part of Research.

The studied periods and selected dynasties and examples are particular causes for developing the pointed discontinuous double-shell dome configuration design that were never surpassed in other periods later on. In fact, these domes reveal the final compositional development of the pointed discontinuous double-shell domes. Figure 4.4

[3] Bulbous domes are typical features of domes in the Saffavid era in Persia and nearby regions.
[4] Refer to the page 181 for extensive elaborations of functions of these building.

exhibits twelve assorted case studies of domes according to the studied periods. Each sample has been evaluated based on its historical and architectural point of views.

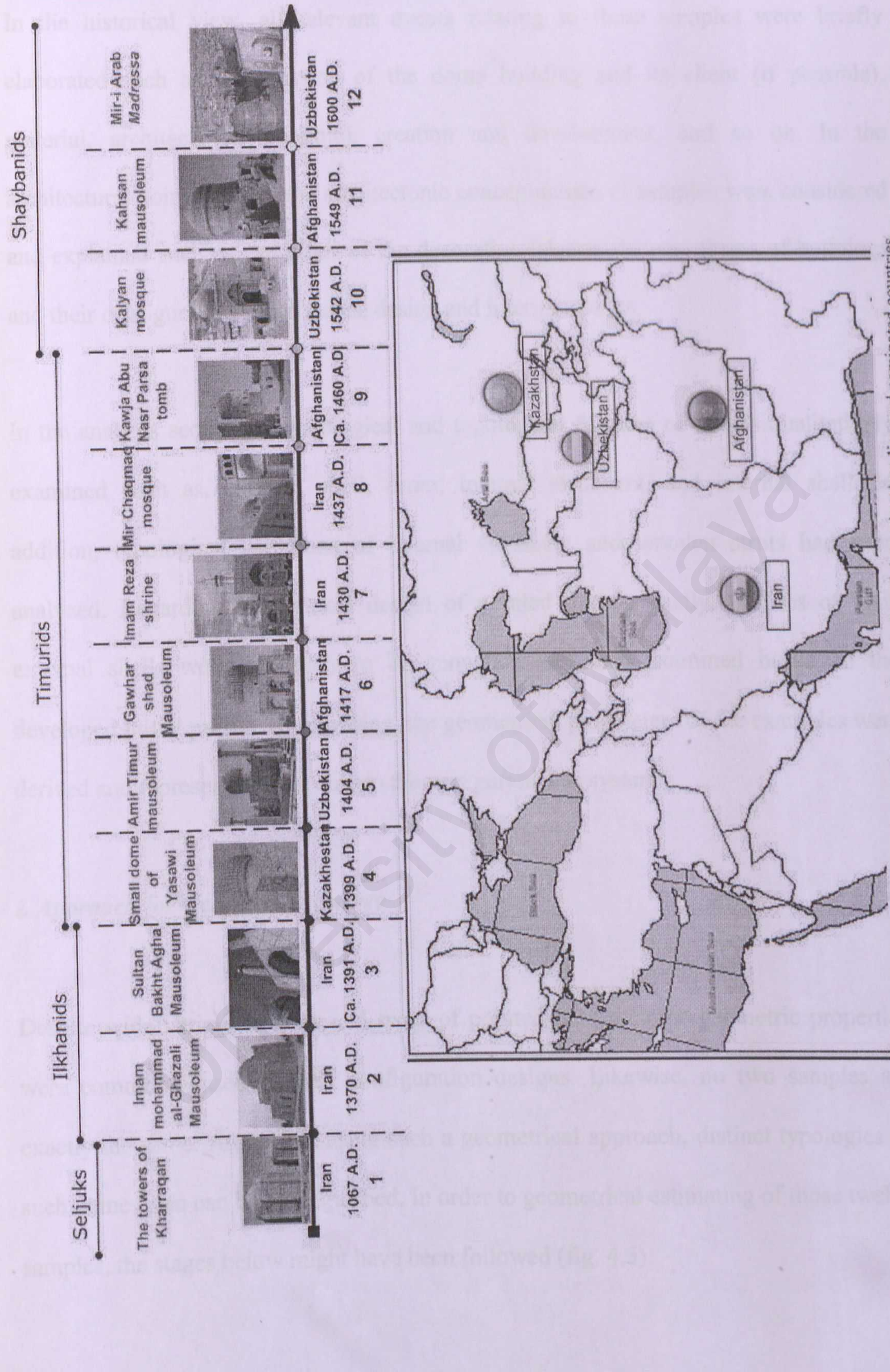


Figure 4.4: Classification of twelve samples according to selected dynasties time line and nominated countries.

In the historical view, all relevant events relating to those samples were briefly elaborated such as, commission of the dome building and its client (if possible), material, architects (if possible), creation and development, and so on. In the architectural point of view, the architectonic conceptualism of samples were considered and explained such as variations of the decorative Islamic themes, forms of buildings and their configuration components, design and internal spaces.

In the analysis section, morphological and typological features of domes qualitatively examined such as, external shell, drum, internal stiffeners, and internal shell. In addition, typological variations of internal stiffeners and wooden struts had been analyzed. Regarding geometrical design of pointed domes, firstly, profiles of their external shells were necessary to be generated and then examined based on the developed initial profile. In following, the geometrical parameters of the examples were derived and represented according to the new parametric system.

i. Approach for Geometrical Survey

Despite wide variety of sizes and types of pointed domes, some geometric properties were commonly used in their configuration designs. Likewise, no two samples are exactly the same. Alongside, using such a geometrical approach, distinct typologies of such domes also can be distinguished. In order to geometrical estimating of those twelve samples, the stages below might have been followed (fig. 4.5):

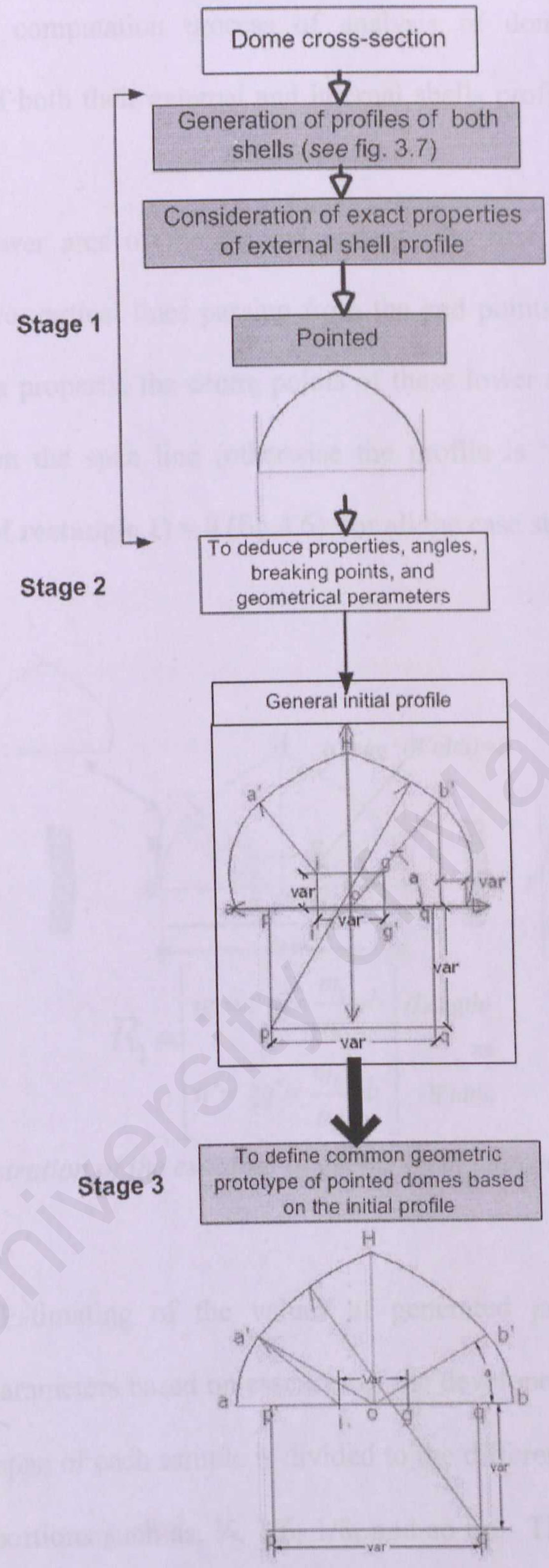
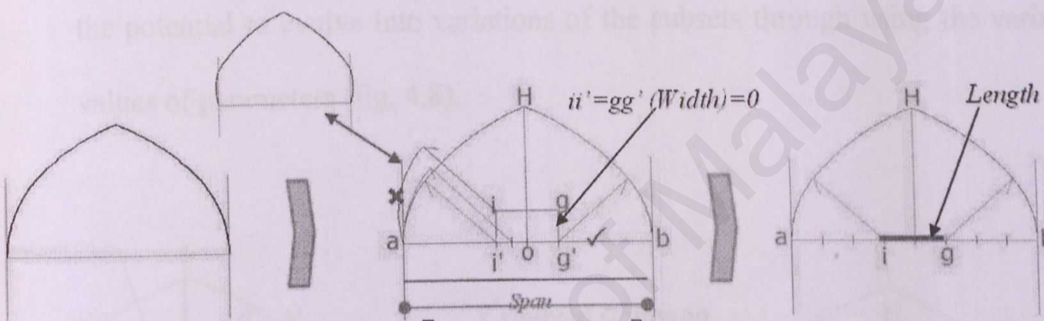


Figure 4.5: A flow chart illustrating the different stages of analyzing and developing a typical generative profile for the pointed discontinuous double-shell domes.

- ***Stage 1:*** The computation process of analysis of domes started with the generations of both their external and internal shells profiles[5] from their cross-sections.

Geometrically lower arcs of the pointed pattern (the first and second arcs) are tangent to the two vertical lines passing from the end points of the span line. For embracing such a property, the centre points of these lower arcs should be located on somewhere on the span line (otherwise the profile is 'bulbous') that means, ii'=gg'; **(width of rectangle 1) = 0** (fig.4.6) for all the case studies;



$$R_1 = \begin{bmatrix} ig = i'g' = \dfrac{m_1}{n_1}ab \\ ii' = gg' = \dfrac{m_2}{n_2}ab \end{bmatrix} \begin{matrix} \text{(Length)} \\ \\ \text{(Width)} \end{matrix} = \begin{bmatrix} ig = i'g' = \dfrac{m_1}{n_1}ab \\ 0 \end{bmatrix}$$

Figure 4.6: Illustration of the essences of geometrical characteristics of the pointed profile.

- ***Stage 2:*** Estimating of the values of generated profile and Deriving its geometric parameters based on essences of the developed general profile. In this regard, the span of each sample is divided to the different parts, according to the certain proportions such as, ¾, 1/6, 1/8, and so on. These derived proportions are calculated as the fractions of the span (e.g. 1/8***ab***, 1/6 ***ab***, …) and then setting them up into the pointed parametric system (*see*, fig. 4.6). The locations of breaking points have been calculated based on the certain angles because of unclear amounts of their vertical lines coordinates (fig. 4.7).

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[5] Refer to Chapter 3 under sub-heading 3.3.3 for more detail about the method of profile generation.

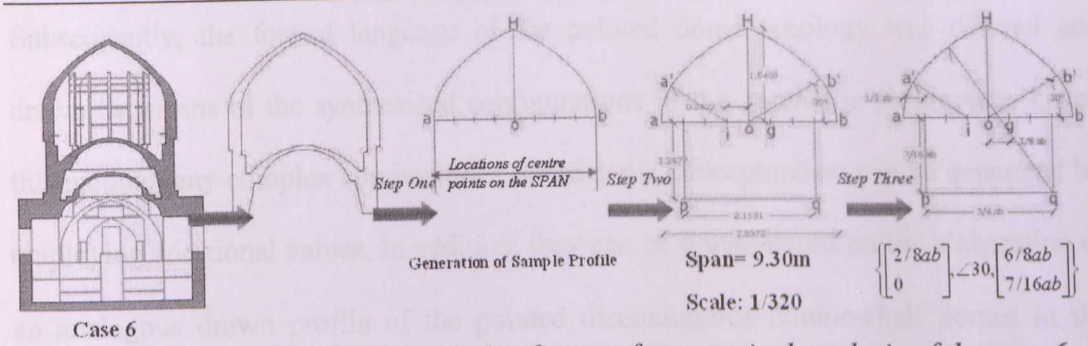


Figure 4.7: Illustration of sample of steps of geometrical analysis of the case 6.

- ***Stage 3:*** Re-modeling the initial profile and obtaining the common prototype of the pointed profile (fig. 4. 5, stage 3): The generated model profile not only presents the typical configuration of the specific pointed typology, but also has the potential to evolve into variations of the subsets through using the variable values of parameters (fig. 4.8).

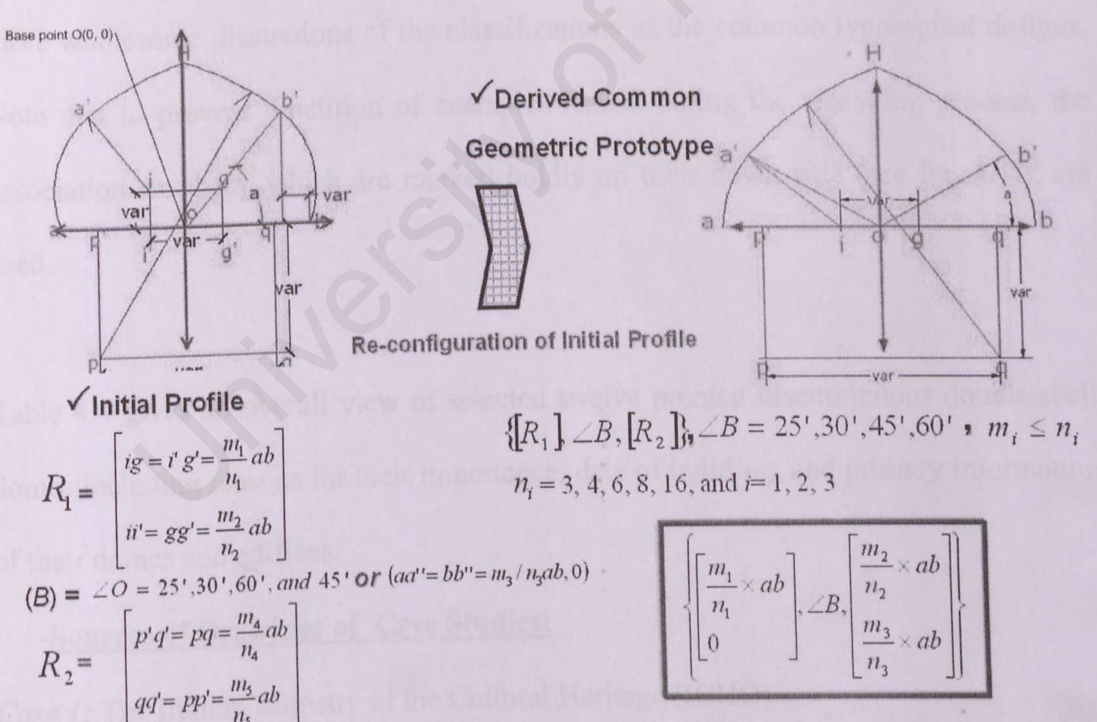


Figure 4. 8: The re-arrangement of initial profile for generating the common geometrical prototype of the pointed discontinuous double-shell domes.

Subsequently, the formal language of the pointed dome typology was derived and drawn by means of the synthesized configurations of the geometric parameters. Using this method, any complex compositions of the dome conceptualism can be generated by employing additional values. In addition, they can be drawn based on the elaboration of an analogous drawn profile of the pointed discontinuous double-shell domes in the modern language[6].

The abundance of the Islamic dome architecture and their diversity in sizes and formations present a problem in generalizing the typologies of the designs. Variations in the shell formations due to conservational interventions or other reasons are ignored, even if the developed initial profile parameters allow analysis of their configurations. Errors and slight inconsistencies in axes, proportions and angles are ignored to facilitate more wholesome discussions of the classifications of the common typological designs. Note that to prevent repetition of examples names during the analyzing process, the association numbers, which are marked boldly on their down side (*see* fig. 4. 4), are used.

Table 4.4 gives an overall view of selected twelve pointed discontinuous double-shell domes including reasons for their importance, date of building, and primary information of their domes and edifices.

-**Sources of Drawings of Case Studies:**

Case 1: The Iranian Ministry of the Cultural Heritage (ICHO)

Case 2: Memarian, 1988; Memarian and Pirniya, 2003; Golombek and Wilber, 1988, Gangler *et al.*, 2004

Case 3: Memarian, 1988; Memarian and Pirniya, 2003; Golombek and Wilber, 1988, Gangler *et al.*, 2004

[6] Refer to Chapter 5 under sub-heading 5.4.2 for more detail about the method of geometric drawing.

Case 4: The architectural office of Vakif Insaat, Turkey; UNESCO restoration document of the Ahmad Yasawi Mausoleum

Case 5: Hillenbrand, 1994; Golombek and Wilber, 1988; Hillenbrand, 1944

Case 6: Memarian, 1988; Memarian and Pirniya, 2003; Golombek and Wilber, 1988, Gangler *et al.*, 2004

Case 7: Pirniya and Bozorgmehri, 1992

Case 8: The Iranian Ministry of the Cultural Heritage (ICHO)

Case 9: The Ministry of Culture & Youth Affairs in Afghanistan

Case 10: Memarian, 1988; Memarian and Pirniya, 2003; Golombek and Wilber, 1988, Gangler *et al.*, 2004

Case 11: The Ministry of Culture & Youth Affairs in Afghanistan

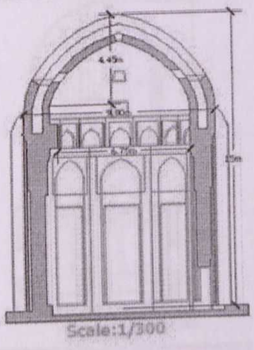
Case 12: Gangler *et al.*, 2004

All cross-sections are entirely redrawn again by Author after transferring their scan JPG to the AutoCAD.

Table 4.4: Brief illustrations of twelve selected case studies.

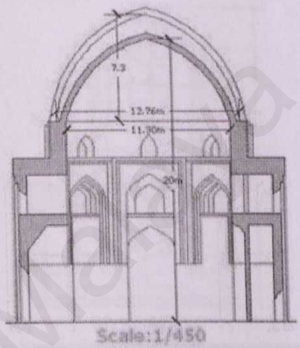
The earliest known of discontinuous double-shell domes are a couple Persian tomb towers in Kharqan. Both the internal and external masonry shells have similar thicknesses and profiles as well as were composed without internal connections and interconnecting wooden struts (Mainstone 2001).

The towers of Kharraqan	Date: 1067 A.D.	Dome height: 15m
	Dome span: 6.75m	

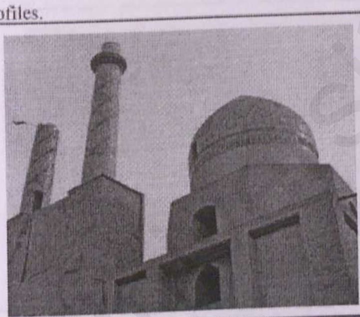


The dome of al-Ghazali tomb is one of the typical domes built in the Khorasan the great after the Seljuk era.

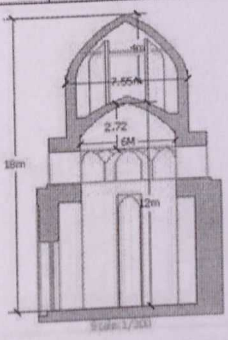
Imam al-Ghazali mausoleum	Date: 1370 A.D.	Dome height: 20m
	Dome span: 11.3 m	



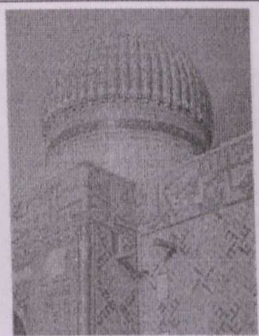
The dome over the Sultan Bakht Aqa tomb adjoining the portal marks a major advance in dome design. It is the earliest known example of a double dome with composition of radial stiffeners and wooden struts in which the inner and outer shells have substantially different profiles.



Sultan Bakht Aqa mausoleum	Date: 1351-52 A.D.	Dome height: 18m
	Dome span: 6 m	



The dome of tomb chamber of Khawaja Ahmad Yasawi is a typical form of the Timurid style with the smaller scale.



Small dome of Yasawi mausoleum	Date: 1389-1399 A.D.	Dome height: 32.5m
	Dome span: 11.33 m	

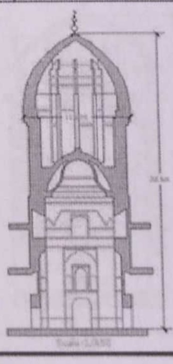


Table 4.4: Brief illustrations of twelve selected case studies (continued).

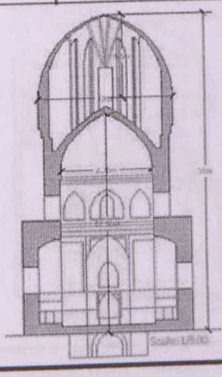
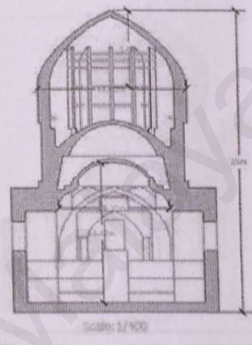
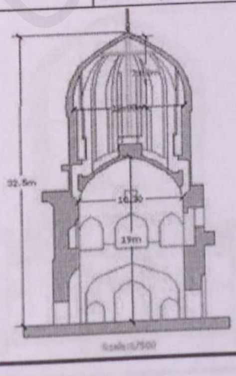
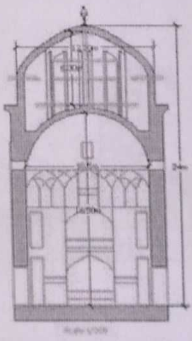
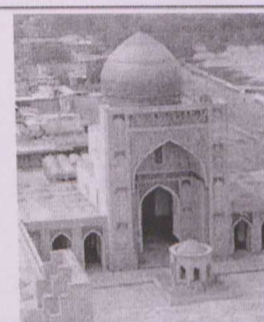
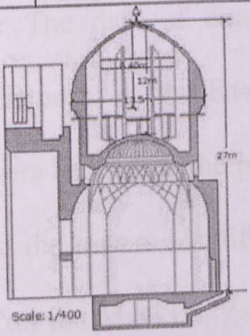
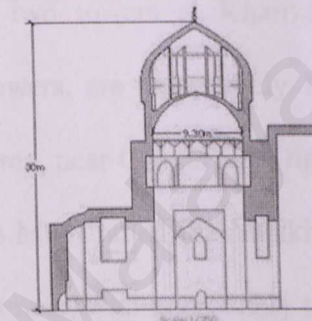
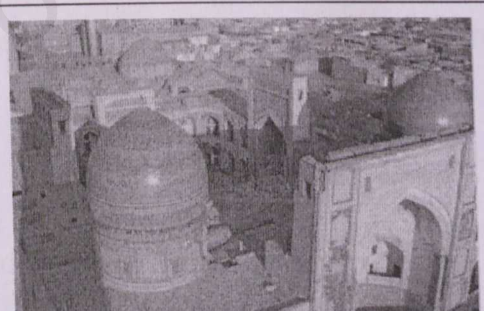
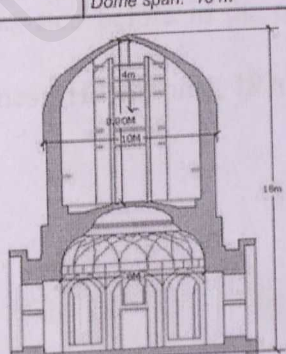
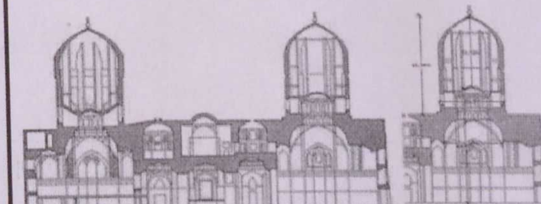
The dome of Timur mausoleum is one of the greatest samples of Islamic domes which was built in the late medieval era. Denserness ornaments and its ribbed fluting dome is expressiveness characteristic of this monument.	The external shell of dome of Gawhar Shad mausoleum is also a typical sample of the Timurid architecture; but its internal shell and composition showed prevailing of the local architectural ornamentations such as using fan-shaped *squinches*.
	
Amir Timur Mauoleum — *Date: 1404 A.D. Dome height: 38m* — *Dome span: 15m*	**Gawhar shad mausoleum** — *Date: 1417-1438 A.D. Dome height: 25m* — *Dome span: 9.3 m*
	
The dome over the Holy shrine of Ali al-Rida is as results of continued developments and constructions since 993 A.D. through in the modern time. Its dome configuration, however, is typical feature of domes of Khorasan the great region.	The Mir-Chaqmaq mosque is built of mud brick finished with white washed with plaster, along the traditional Iranian four-iwan structure around a square courtyard with no minarets. The shallow pointed dome rested on large mini-arches squinches in a two-tiered circular drum, adorned with bands of glazed inscription tiles in Kufic script.
	
Imam ali al-Riza Shrine — *Date: 1430 A.D. Dome height: 32.5m* — *Dome span: 10.7 m*	**Mir Chaqmaq mosque** — *Date: 1437 A.D. Dome height: 24m* — *Dome span: 10.50 m*
	

Table 4.4: Brief illustrations of twelve selected case studies (continued).

The dome of Khawaja Abu Nasr Parsa mausoleum is considered as only remained fluted sample of the international dome characteristic of the Timurid architecture outside of Uzbekistan. Its domes was underwent major conservation interventions in uncertain date.	The dome of Kalyan mosque resulted mainly date back in the Shaybanid dynasty. The original dome was destroyed by fire as a result of Mongolian invasion.
	
Khawja Abu Nasr Parsa mausoleum — *Date: c. 1460-1598 A.D.* — *Dome span: 13.5m* — *Dome height: 27m*	**Kalyan mosque** — *Date: 1542 A.D.* — *Dome height: 30m* — *Dome span: 9.30 m*
	
Its dome is one of the valuable relics remained from the Timurid time. The existing evidences, however, are not enough for considering whole its details. Nevertheless, the origin of building belonged the before Timurid era.	The domes over Mir Arab madrasa are considered as the common aspects of Shaybanid architecture which domes were often built in pair.
	
Kahsan mausoleum — *Date: 1549 A.D.* — *Dome height: 18m* — *Dome span: 10 m*	**Mir-I Arab *madressa*** — *Date: 1600 A.D.* — *Dome height: 29m* — *Dome span: 10 m*
	

4.3.1 Case Study 1: The Twin Towers of Kharaqan, Iran

Location: Kharraqan, Iran

Date: 1067 and 1093 A.D.

Style/Period: Seljuk/ 11th Century

Building Type: Funerary

Building Usage: Mausoleum

i. History: The date of construction for the two towers at Kharraqan which commonly referred to as the East and the West towers, are respectively 1067-8 and 1093. The towers located on the plains in northern Iran, near Qazvin city (fig. 4.9). The inscriptions on the towers identify the architects as Muhammad ibn Makki al-Zanjani and Abu'l-Ma'ali ibn Makki al-Zanjani in the later tower, who is probably the former's son or brother. The brick structures stand 15 meters tall and 4 meters wide, and make the extensive use of geometry. These are remnant examples of Seljuk architecture remained in Persia (Mainstone, 2001).

Both towers were significantly damaged in an earthquake in 2001. This is one of the earliest applications of a pointed dome over the tomb tower. The tradition of a double dome had existed before in the early Islamic architecture by constructions of various conical domes [7](Hillenbrand, 1976).

[7] For more information regarding conical domes in the early Islamic architecture refer to (Ashkan and Yahaya, 2009)

Conservation process of tombs after Earth quake 2001

Exterior view of tomb towers

Figure 4.9 : Illustrations of the exterior views of the tomb towers (The Iranian Ministry of the Cultural Heritage) .

ii. Architecture**:** Both towers have octagonal chambers with engaged pilasters at every corner. Each of the eight facades of the two towers is adorned with a decorative panel. Each tower is made of thick brick walls whose decorative brick panels have been attached (Memarian and Pirniya, 2003). The east tower has a north-east facing entrance while the West tower entrance is to the north. Two of the buttresses at the Eastern tower contain spiral staircases within them. This is different at the Western tower where only one of the buttresses contains a staircase. Both tombs were built with the pointed discontinuous double shells; the exterior shells, however, have not survived (fig. 4.10) (Memarian and Pirniya, 2003).

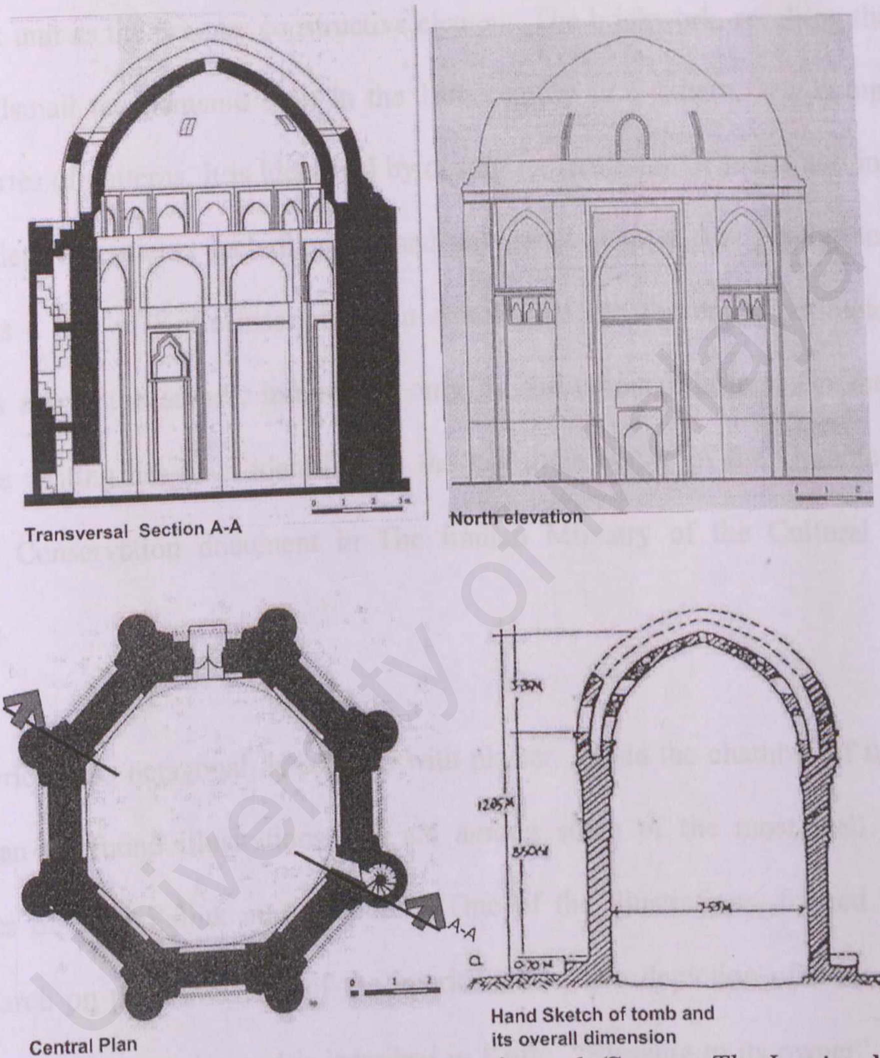


Figure 4.10: Various architectural drawings of case 1 (Source: The Iranian Ministry of the Cultural Heritage).

The common feature of the panels in both towers is a decorative niche flanked by a pair of slender columns. Framed by the corner buttresses, these panels are minor variations of the same decorative theme. In the west tower, the panel within the niche has been divided into two parts, slightly protruding, arched niches. The top and the bottom parts of the panel have been decorated differently with varying weave patterns. In the east tower, built first, these panels have been left uninterrupted and only include one pattern per panel (Source: Conservation document in The Iranian Ministry of the Cultural Heritage (ICHO)).

All panels are distinguished by a different decorative pattern but are unified in their use of a brick unit as the primary constructive element. The brickwork, recalling the earlier tomb of Ismail the Samanid built in the 10th century in Bukhara, is a complex and varied series of patterns. It is identified by deeply recessed mortar joints and includes a wide variety of patterns including star and polygonal shapes. Also, common in both towers, is a line of Kufic inscriptions in Arabic that run the entire perimeter of the buildings above the arches, interrupted only by the corner pilasters. On the eastern tower the writing has been identified as the last three verses of the Quranic Sura 59 (Source: Conservation document in The Iranian Ministry of the Cultural Heritage (ICHO)).

The interior, also octagonal, is covered with plaster. Inside the chamber of the eastern tower can be found illustrations that are among some of the most well preserved examples of early Seljuk mural painting. One of the illustrations, framed by a keel shaped arch on the lower side of the interior walls, is a depiction of a mosque lamp hanging with three chains and is inscribed in Kufic: “Blessing to its owner”. The other illustration is a stylized design of birds sitting in the branches of a pomegranate tree.

The bases of the towers have suffered great damage due to the rising water level and have only informally been repaired by the local people. The western tower, having had the structural advantage given to it by the elimination of a second stair inside its buttress, has survived more intact (Source: Conservation Document in the Iranian Ministry of the Cultural Heritage (ICHO)).

***iii. Analysis*:** Both tomb towers had been constructed according to similar concepts and components (fig. 4.11a). Both shells were built without the drum with similar thicknesses (fig. 4.11 d) and rested on the hexagonal load bearing shape (fig. 4.8 c). Morphologically, the considerations of four vocabularies of dome did not show any specific development in the architectural concept (fig. 4.11a). Their transition tiers also showed neither specific developments in configuration nor in design (fig. 4.11b). It consists of a row of high vaulted niches with rectangular frames. Considerations of the remains of their damaged external clearly demonstrated the lack of design and construction knowledge that caused their damaging. As for the grammar of dome or its typology, it is considered as simple without drum.

Resulting from geometrical analysis based on the general profile characteristics, its generated profile is considered as the four-centered profile for both the internal and external shells which can be formulated according to the following geometrical parameters (fig. 4.11 e):

External and Internal shells: $\left\{ \begin{bmatrix} 2/10ab \\ 0 \end{bmatrix}, \angle 30, \begin{bmatrix} 4/10ab \\ 4/10ab \end{bmatrix} \right\}$

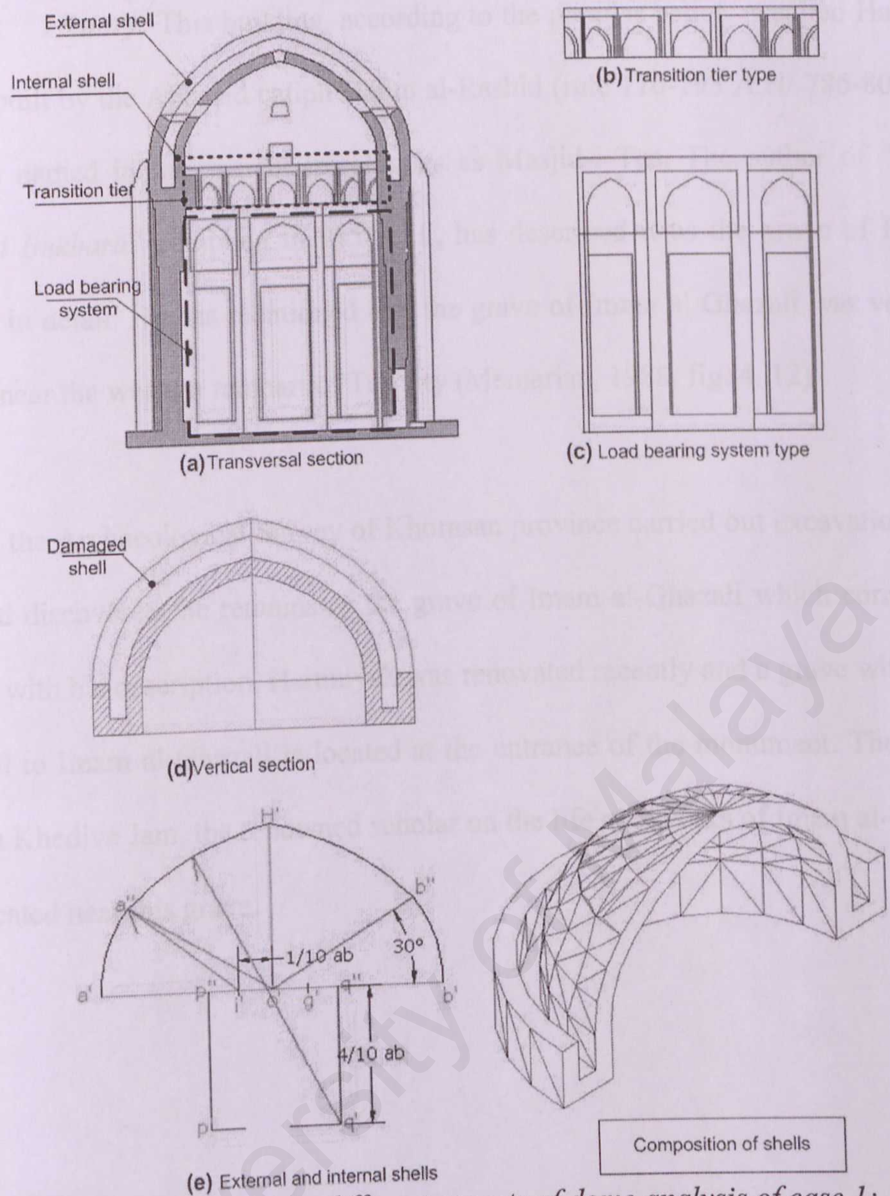


Figure 4.11: Illustrations of the different aspects of dome analysis of case 1: Morphological survey, typological survey, geometrical survey.

4.3.2 Case Study 2: Imam Mohammad al-Ghazali Tomb, Iran

Variant Names: Imam Mohammad al-Ghazali Tomb

Location: Tus, Iran

Date: early 1400 A.D.

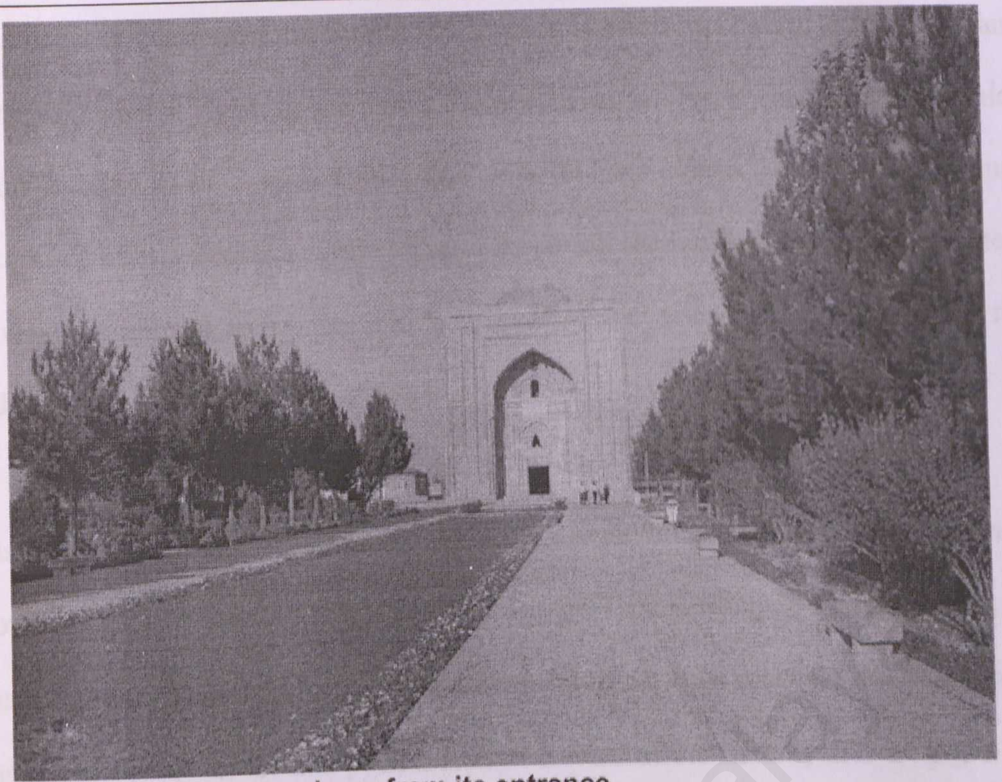
Style/Period: Ilkhanid/ 14th century

Building Type: Funerary

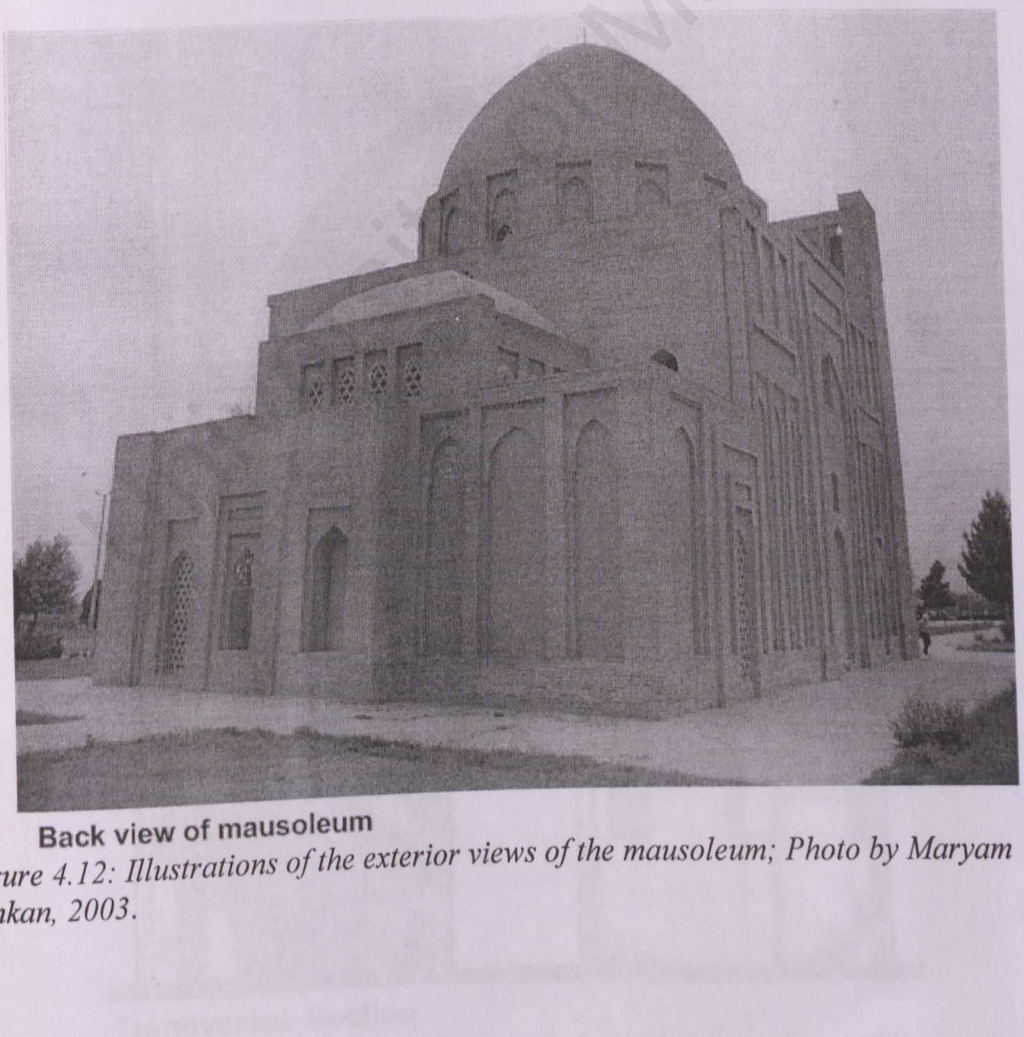
Building Usage: Tomb

i. ***History:*** This building, according to the popular belief, is called Haruniyah, the jail built by the Abbasid caliph Harun al-Rashid (rule 170-193 A.H/ 786-809 A.D.), but it is named in the ancient travelogues as Masjid-i Tus. The author of "*Mihman Namah-i Bukhara*" compiled in 915 A.H., has described it as the grave of Imam al-Ghazali in detail. He has mentioned that the grave of Imam al-Ghazali was very small located near the western rampart of Tus city (Memarian, 1988; fig. 4. 12).

In 1995 the Archaeological Survey of Khorasan province carried out excavations in this area and discovered the remains of the grave of Imam al-Ghazali which corresponded exactly with his description. Haruniyah was renovated recently and a grave with epitaph ascribed to Imam al-Ghazali is located at the entrance of the monument. The grave of Husayn Khedive Jam, the renowned scholar on the life and works of Imam al-Ghazali is also located near this grave.



Main view of mausoleum from its entrance



Back view of mausoleum

Figure 4.12: Illustrations of the exterior views of the mausoleum; Photo by Maryam Ashkan, 2003.

ii. ***Architecture***: the monument is made of bricks. Its height is 25 meters and it covers an area of 144 square meters and consists of three chambers. The middle chamber consists of a *mihrab* decorated with intricate stucco work. Typical valuable decorative brick works run surrounding every part of the building including the external elevation prominent arches, blind niches, transition tier with its unique *muqarnas* rings and arched recess (Memarian, 1988).

It is interesting to note the utilization of several wind towers in different directions for providing natural interior ventilation. The internal spaces include entrance *iwan*, four chamber halls, dome hall and three ancillary rooms. A huge rectangular garden, which was re-built based on the first plan, is located in front of the Haruniyah *iwan* (fig.4.13).

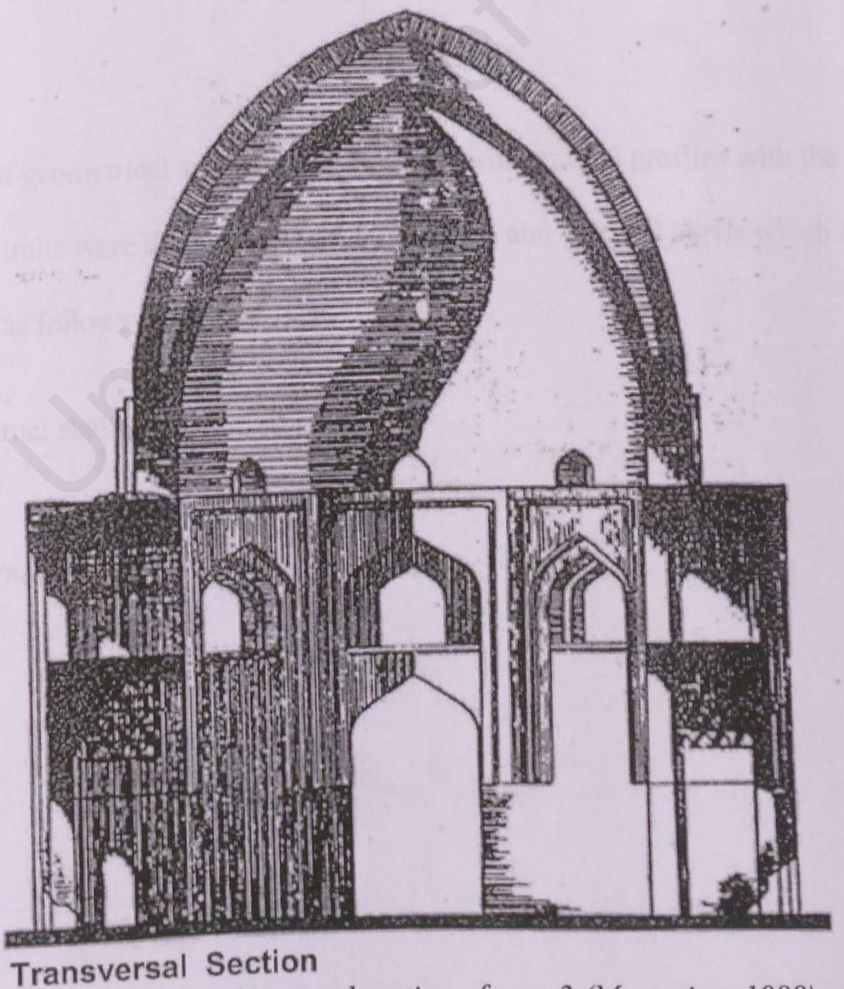


Figure 4.13: Architectural section of case 2 (Memarian, 1988).

iii. ***Analysis:*** the massive scale and composition of building is very similar to Sultan Sanjar mausoleum (in Merv). The load bearing system is composed of the symmetrical empty and blind arch with solid walls (fig. 4.15, c). Although, the external shell was damaged, yet signs of brick connections between the two shells have remained. The height of shells had been increased over time as well as they were built with similar thicknesses on the many-sided drum which showed a developed formation than the previous ones (fig. 4. 14, a).

It consists of high vaulted niches with rectangular frames and openings placed in regular positions. Section consideration of the external shell clearly demonstrated the lack of design and construction knowledge that caused its damaging (fig. 4.14, d). In terms of the grammar of dome organization or dome typology it is considered as simple with drum.

As a result of geometrical analysis, two types of two-centered profiles with the different geometrical traits were derived for both the internal and external shells which these can be arranged as follows (fig. 4.14, e, f):

- External shell: $\left\{\begin{bmatrix} 2/4ab \\ 0 \end{bmatrix}, 0, \begin{bmatrix} 0 \\ 0 \end{bmatrix}\right\}$; and
- Internal shell: $\left\{0, 0, \begin{bmatrix} 6/8ab \\ 2/8ab \end{bmatrix}\right\}$.

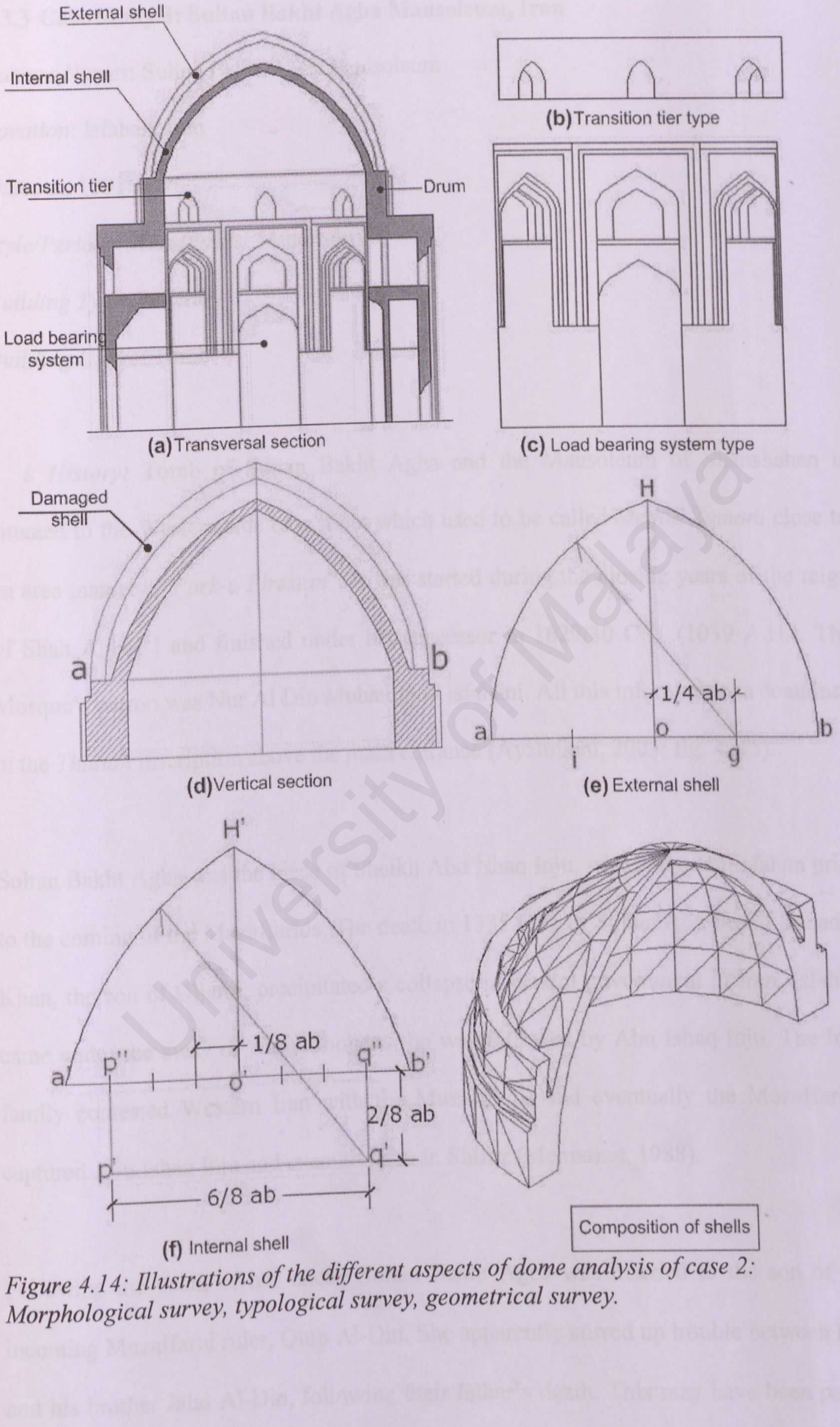


Figure 4.14: Illustrations of the different aspects of dome analysis of case 2: Morphological survey, typological survey, geometrical survey.

4.3.3 Case Study 3: Sultan Bakht Agha Mausoleum, Iran

Variant Names: Sultan Bakht Agha Mausoleum

Location: Isfahan, Iran

Date: ca. 1391 A.D.

Style/Period: Muzaffarids/ 14thcentury

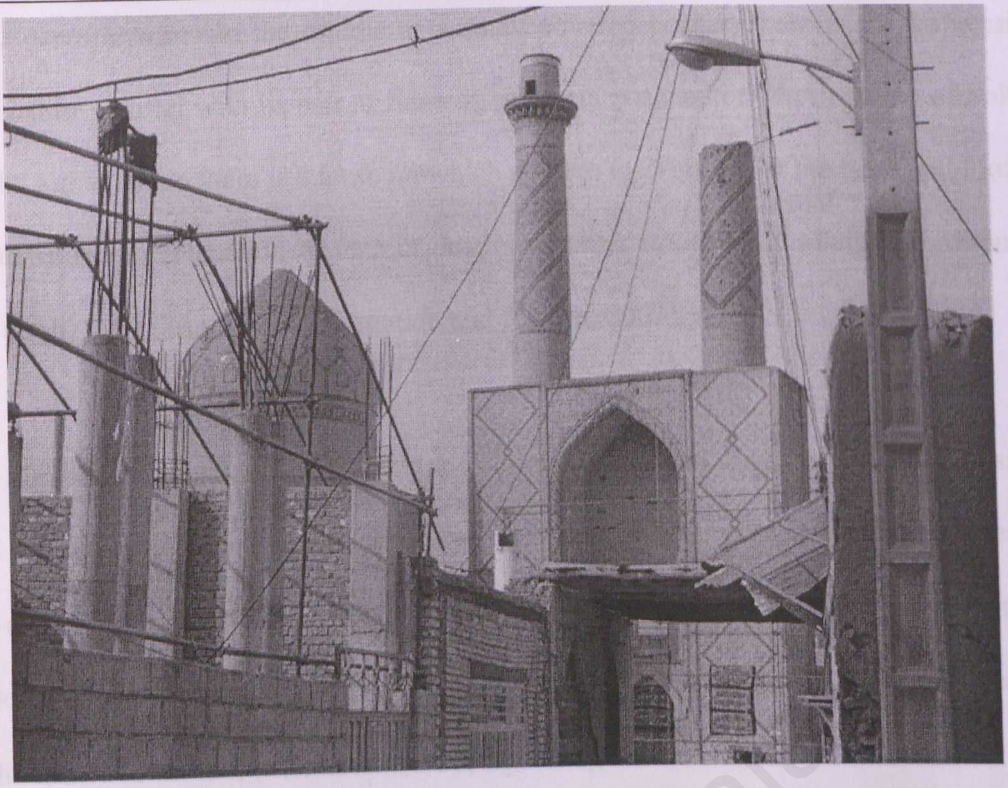
Building Type: Funerary

Building Usage: Tomb

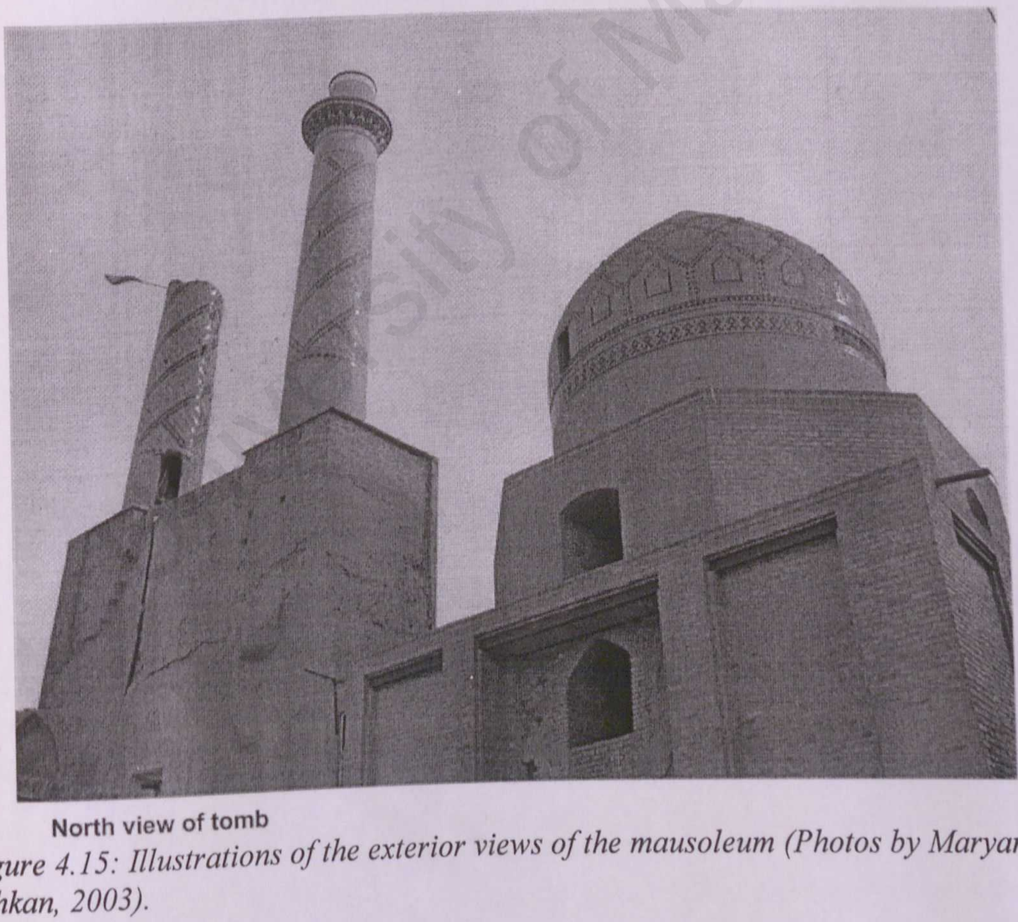
i. History: Tomb of Soltan Bakht Agha and the Mausoleum of Shahshahan is situated to the Western side of a street which used to be called *Shahid Zamani* close to an area ,namely, "*Park-e-Pirestan*". It was started during the closing years of the reign of Shah Abbas I and finished under his successor in 1629/30 C.E. (1039 A.H.). The Mosque's patron was Nur Al Din Muhammad Isfahani. All this information is contained in the *Thuluth* inscription above the main entrance (Ayatollahi, 2003; fig. 4. 15).

Soltan Bakht Agha was the niece of Sheikh Abu Ishaq Inju, who had ruled Isfahan prior to the coming of the Muzaffarids. The death in 1335 C.E. of Sultan Abu Seyed Bahadur Khan, the son of Oljeitu, precipitated a collapse in central government in Iran. Isfahan came under the sway of Amir Chogan who was followed by Abu Ishaq Inju. The Inju family contested Western Iran with the Muzaffarids and eventually the Muzaffarids captured Abu Ishaq Inju and executed him in Shiraz (Memarian, 1988).

Following the death of her uncle, Soltan Bakht Agha was married to the son of the incoming Muzaffarid ruler, Qutb Al-Din. She apparently stirred up trouble between him and his brother Jalal Al-Din, following their father's death. This may have been partly to avenge the death of her uncle. She also appears to have attempted to betray Isfahan, which had been given to her husband, to her brother-in-law. Her husband heard of the plot and had her executed, but he still lost Isfahan to his brother in 1375 A.D. The construction of this building may be by orders of Jalal Al-Din that this splendid monument was erected to honor the woman who had tried to help him and at the same time avenge her uncle's death (Ayatollahi, 2003).



South view of tomb



North view of tomb

Figure 4.15: Illustrations of the exterior views of the mausoleum (Photos by Maryam Ashkan, 2003).

ii. Architecture: In the middle of a small covered bazaar, there is the impressive 14th century portal with its pair of flanking minarets attached beside the tomb of Soltan Bakht Agha. Inside there is a tomb on which are two inscriptions at the head and foot of the tomb (i.e., explanation of date of death and other information about the patron of this tomb) (Memarian, 1988; Memarian and Pirniya, 2003).

The dome over the chamber adjoining the portal marks a major advance in dome design. It is the earliest known example of a developed double-shell dome in which its internal and external shells have substantially different profiles. Blue glazed tiles partly adorn all building surfaces. The dome chamber is almost square in shape with the grave located in the center of the hall (Memarian, 1988; fig. 4.16).

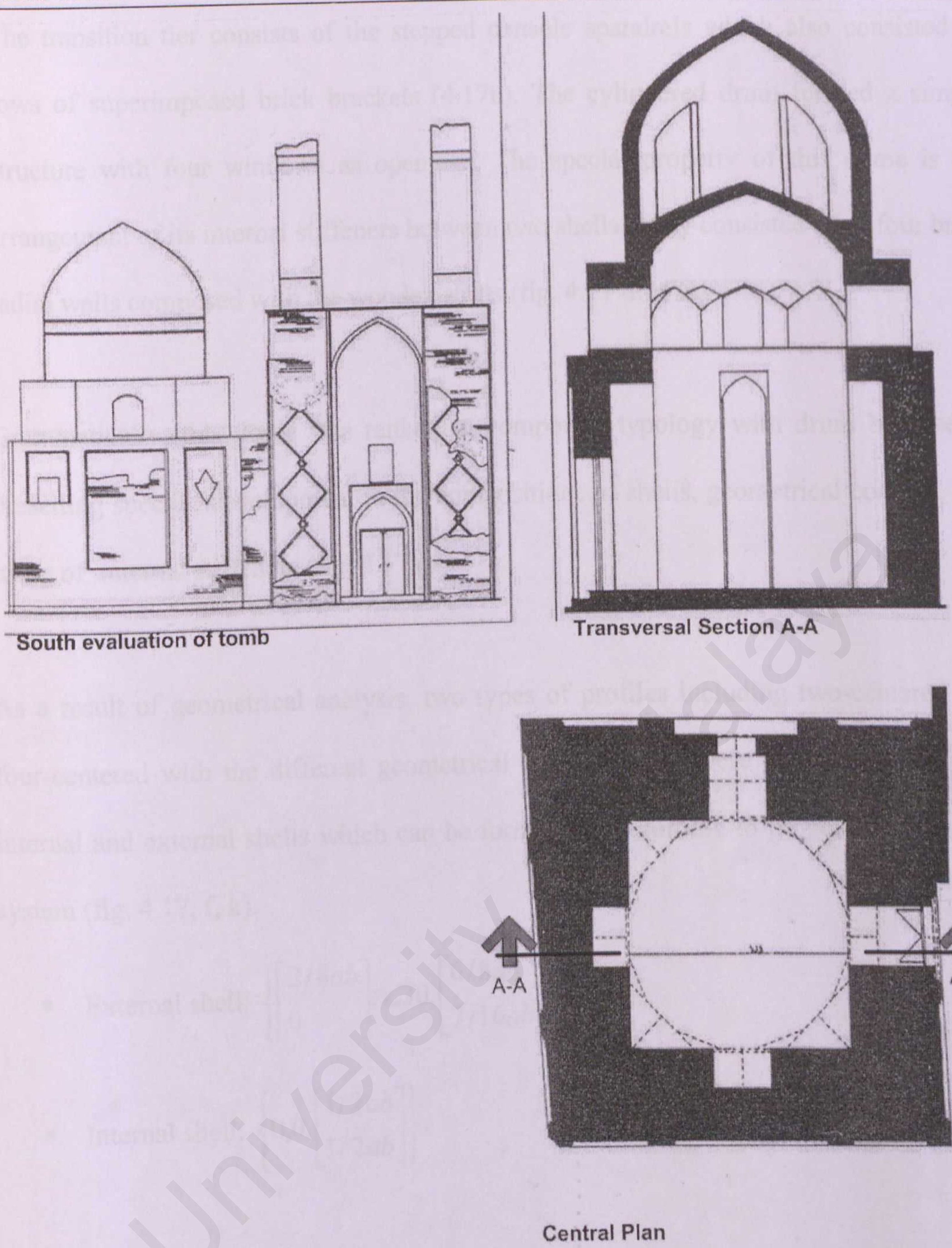


Figure 4. 16: Various architectural drawings of case 3 (Memarian and Pirniya, 2003).

iii. Analysis: This is the primary completed example of the compositional concept of pointed discontinuous double-shell dome in the Middle East and Central Asia. From the morphological point of view, there exists no similarity between the shapes of external and internal shells (4.17a). Thicknesses of both shells gradually reduced from the base to the top of the dome. Its load bearing system is solid walls composed with blind arches (4.17c).

The transition tier consists of the stepped console spandrels which also consisted of rows of superimposed brick brackets (4.17b). The cylindered drum formed a simple structure with four windows as openings. The special property of this dome is the arrangement of its internal stiffeners between two shells. They consisted of of four brick radial walls composed with the wooden struts (fig. 4.17 d, e; fig 4.18).

Grammatically, this dome was ranked in compound typology with drum because of presetting specific development in the compositions of shells, geometrical concept, and using of internal stiffeners (fig. 4.17a).

As a result of geometrical analysis, two types of profiles including two-centered and four-centered with the different geometrical characteristics were derived for both the internal and external shells which can be formulated according to proposed parametric system (fig. 4.17, f, k):

- External shell: $\left\{\begin{bmatrix}2/8ab\\0\end{bmatrix},\angle 30,\begin{bmatrix}6/8ab\\7/16ab\end{bmatrix}\right\}$; and
- Internal shell: $\left\{0,0,\begin{bmatrix}1/2ab\\1/2ab\end{bmatrix}\right\}$.

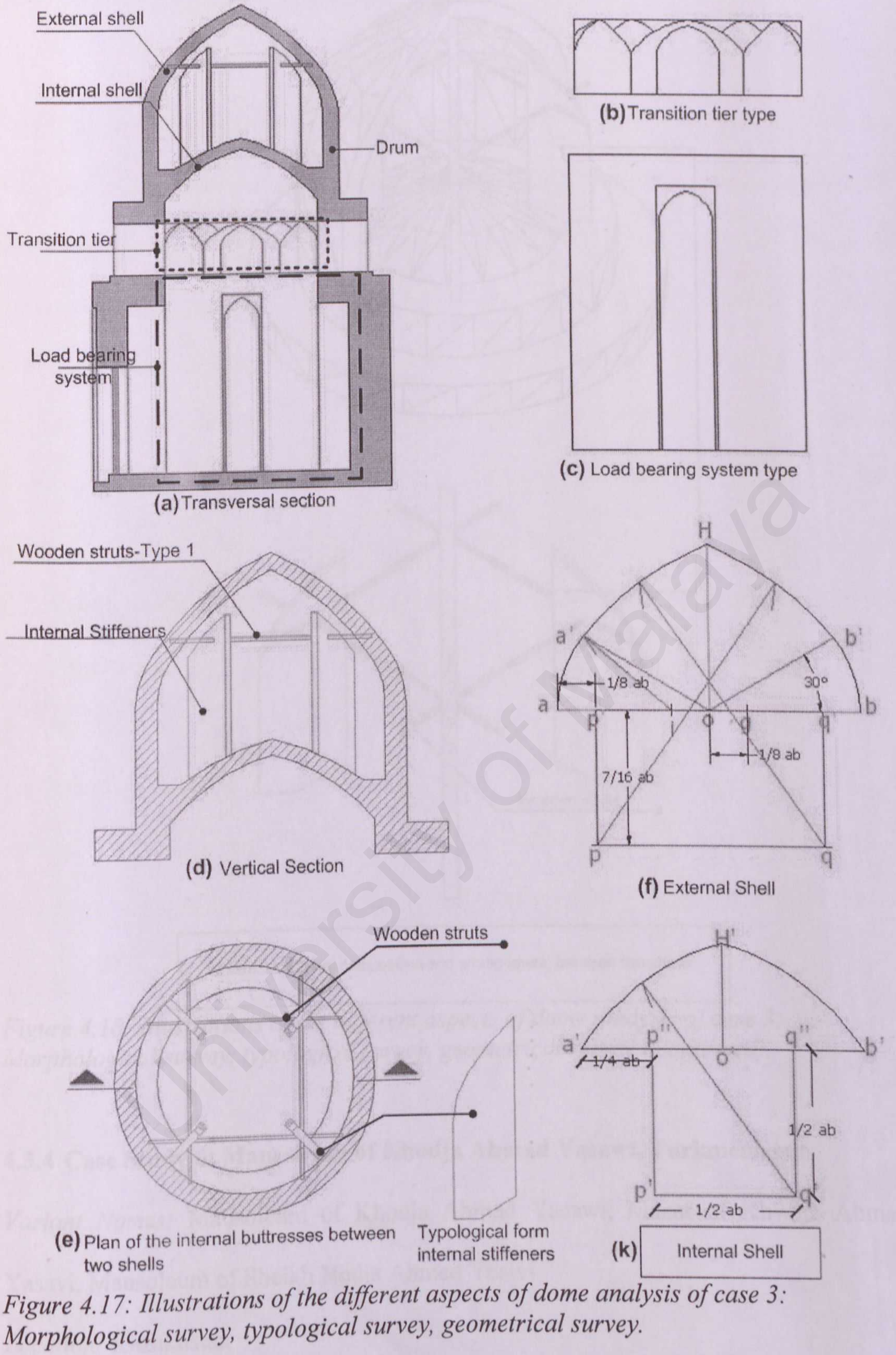


Figure 4.17: Illustrations of the different aspects of dome analysis of case 3: Morphological survey, typological survey, geometrical survey.

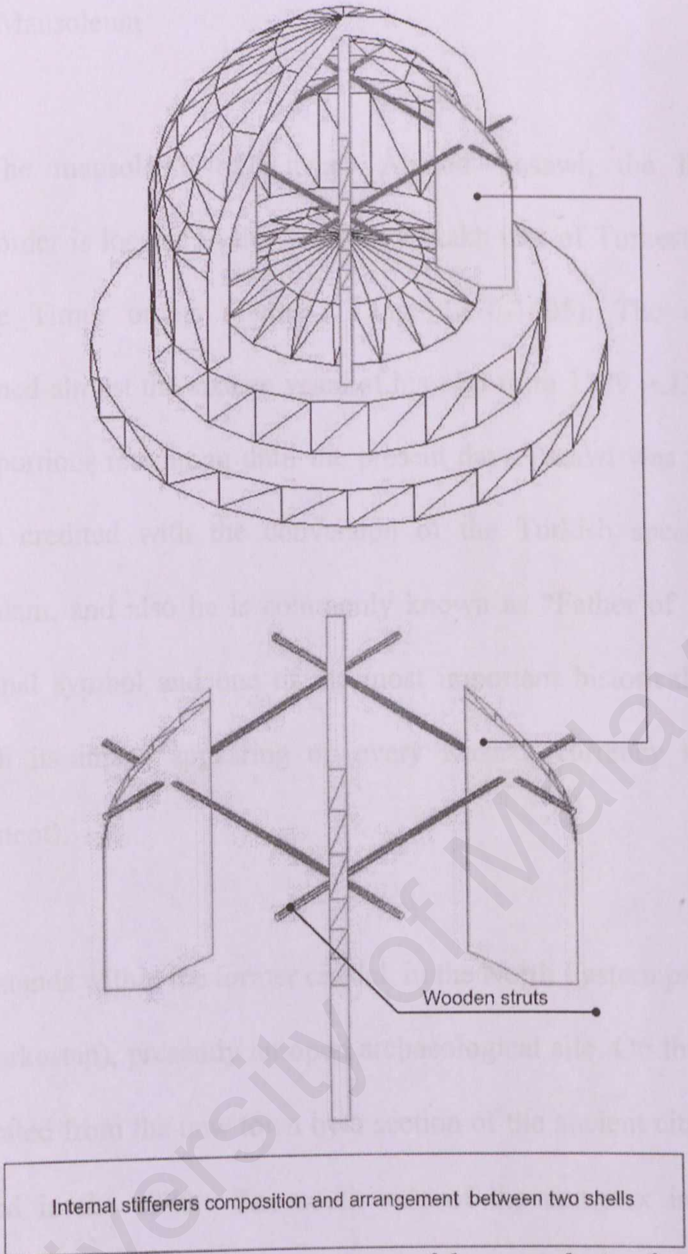


Figure 4.18: Illustrations of the different aspects of dome analysis of case 3: Morphological survey, typological survey, geometrical survey (Continued).

4.3.4 Case Study 4: Mausoleum of Khodja Ahmad Yasawi, Turkmenistan

Variant Names: Mausoleum of Khodja Ahmad Yasawi, Mazar of Khwaja Ahmad Yasavi, Mausoleum of Sheikh Hodja Ahmed Yesivi

Location: Kazakhstan

Date: 1389 -1405 A.D.

Style/Period: Timurid/ 14th Century

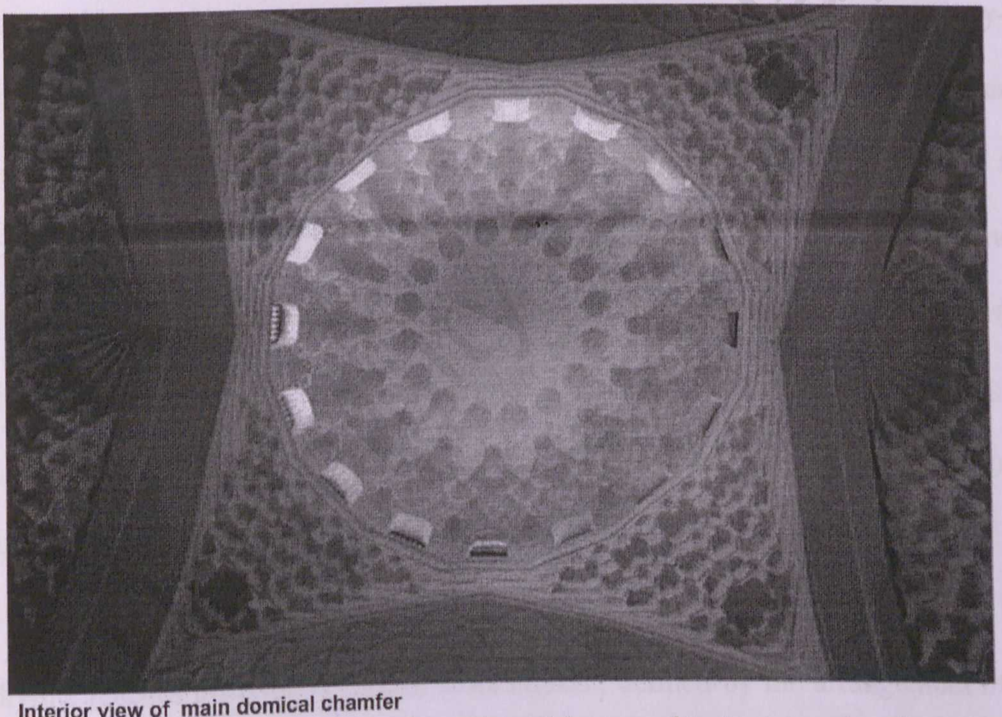
Building Type: Funerary

Building Usage: Mausoleum

i. History: The mausoleum of Khwaja Ahmad Yasawi, the founder of the Yasawiyya Sufi order is located in the southern Kazakh city of Turkestan. It was built according to the Timur orders (Timur-i Lang; 1370-1405). The construction of mausoleum spanned almost the sixteen years of his rule from 1389 A.D. to 1405 A.D., with unfinished portions remaining until the present day. Yasawi was a Sufi poet and teacher who are credited with the conversion of the Turkish speaking people of Kazakhstan to Islam, and also he is commonly known as "Father of the Turks". His shrine is a national symbol and one of the most important historical monuments in Kazakhstan, with its image appearing on every Kazakh currency note (UNESCO restoration document).

The mausoleum stands within the former citadel, in the North Eastern part of the ancient town of Yasi (Turkestan), presently an open archaeological site. On the north side, the complex is separated from the new town by a section of the ancient citadel wall, which was reconstructed in the 1970. The south side of the complex is occupied by a protected natural area; the modern city of Turkestan surrounds it on the remaining other sides ((UNESCO restoration document; fig.4.19).

Main view of mausoleum from its entrance



Interior view of main domical chamfer

Figure 4.19: Illustrations of views of exterior of dome and its interior chamber (UNESCO restoration document).

ii. ***Architecture***: The mausoleum was originally built at the 12th century; but its older materials and smaller size of mausoleum were replaced. The portal of the shrine was later completed by the Shaybanid ruler Abdullah Khan (1583-1598) in 1591. In the early nineteenth century, Khudayar Khan of Kokand (1845-1875) had turned the mausoleum into a fortress by building a wall around it ((UNESCO restoration document; fig. 4.20).

The 1864 bombardment of the city by Tsarist troops severely damaged the external walls of this complex. The shrine was subsequently used as a military depot by the Soviets after which it was under continuous restoration since 1907. A recent restoration and publicity effort, financed by the government of Turkey, was carried out between 1992 and 2000, until the monument was finally added to the World Heritage list in 2003 (UNESCO restoration document).

On the architectural point of view, This mausoleum is rectangular in plan (forty-six meters by sixty-three meters), comprising eight main chambers, twenty-seven small rooms and twelve passages, all enclosed within a single building and spread over two floors (fig. 4. 20, central plan). The complex is aligned along the Southeast-Northwest axis consisting, in order of visit, a magnified portal, a large assembly hall (*kazandyk*), the Khwaja's tomb chamber (*gur khana*) and several ancillary structures flanking the axis, such as a refectory (*ash khana*), library (*kitab khana*), small palace (*aq saray*), a mosque and a sacred well.

Its skyline reaches thirty-eight meters at its highest, defined by the arrangement of the colossal portal and the dome of the assembly hall. The lack of surface treatment on the portal and the incomplete minarets flanking its sides give evidence to the unfinished state of the monument (UNESCO restoration document).

The main entrance to the complex is from the southeast through the deep portal niche into the large square assembly hall (eighteen square meters), which is covered with a pointed dome, the largest ever built in the Central Asia. The dome is clad with a mosaic of light blue tiles on the exterior and is raised on a square and octagonal drum to the height of the portal. The center of the assembly hall is occupied by a bronze cauldron (*kazan*, dated 1399) used for rituals (UNESCO restoration document).

To the Northeast and Southwest sides of the hall are two dark pairs of small rooms that probably served as rooms for confinement and reflection (*chilleh khanas*). Beside these, but entered only from the northern corridors are rectangular rooms with arched recesses. The larger room to the southwest serves as a library. The one to the northeast is known as the "small palace" (*aq saray*). In the southern corner of the building is a narrow, rectangular kitchen (*khalim khana*), which has three two-story units. In the eastern corner is a large square room with a well and only one two-story unit (*kuduk khana*) (UNESCO restoration document).

The tomb chamber of Khawaja Ahmad Yasawi is located on the northwest axial terminus. Its center is occupied by the sarcophagus of the Sufi saint. The chamber has a double dome with green and golden decorated tiles that cover the outer ribbed dome (fig.4.20, *see* transversal section). The drum of the dome is tiled with hexagonal green glazed tiles adorned with geometric patterns in gold. To the southwest of the tomb is a small mosque of rectangular form with very deep arched recesses. Cut into these four corners outside these alcoves are four sets of staircases. The mosque is covered by a dome resting on arches. The mosque has a mosaic faience *mihrab*. The mausoleum and the mosque are also entered directly from the portals on the northwest façade (UNESCO restoration document).

The decoration of the shrine complex is concentrated on the exterior. The interior decoration is limited to plaster *muqarnas*, carvings in the dome surface and *squinches* of the assembly hall, the mausoleum and the mosque. The dados of the assembly hall and mosque are formed of hexagonal green tiles. Almost all of the exterior ornamentation is in glazed tile. The large surfaces of the north, east and west facades are covered in brick mosaic (*hazarbaf*), forming great expanses of geometric patterns with some Kufic inscriptions. Though each façade has a different overall pattern, they are tied together through a continuous stone mosaic band at the base made of geometric patterns on *haft rangi* tiles. The three facades are also consolidated by a continuous Nakshi inscription that runs below the crenellated parapet of the roof, executed in brick mosaic (UNESCO restoration document).

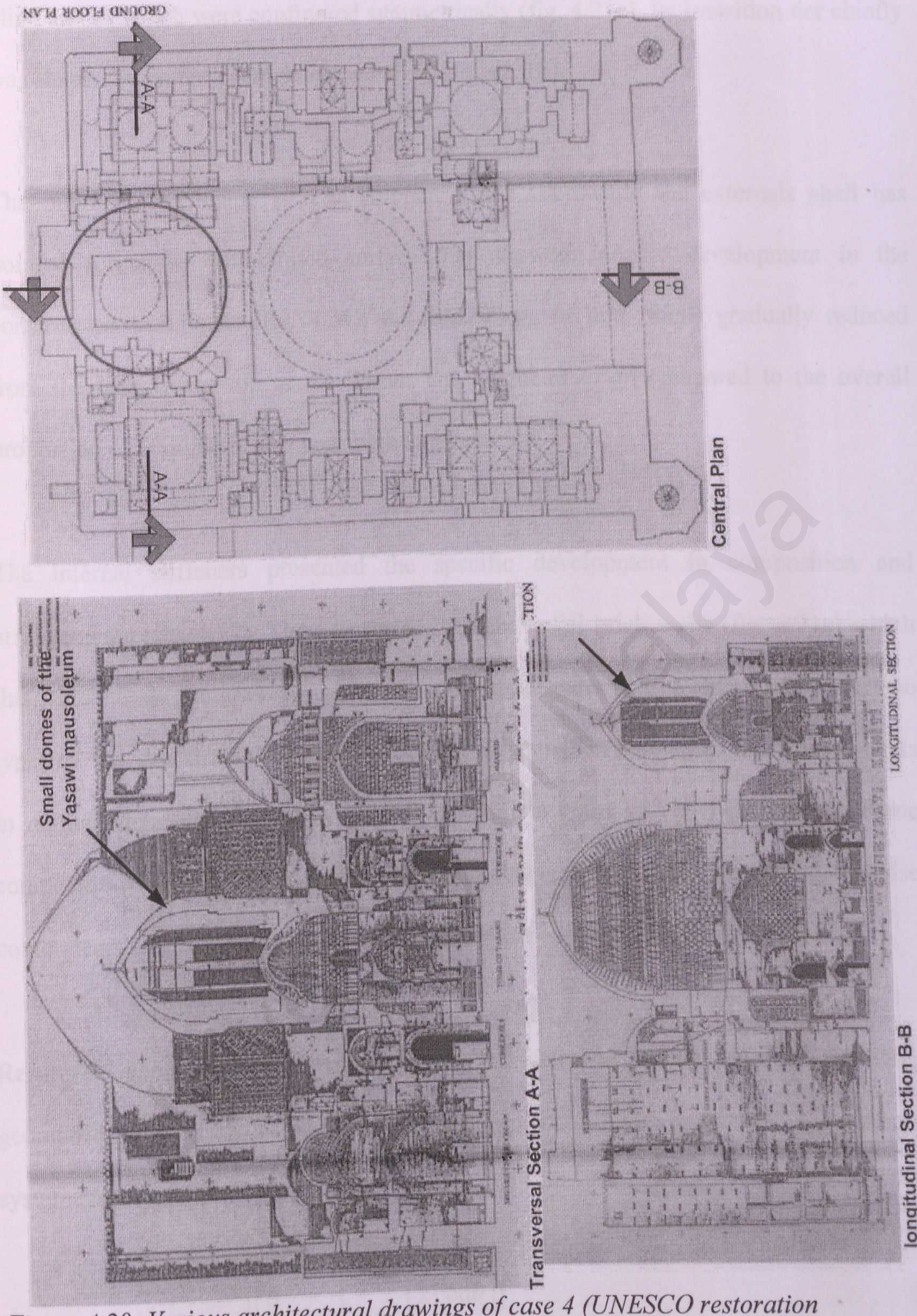


Figure 4.20: Various architectural drawings of case 4 (UNESCO restoration document).

iii. Analysis: In general, complexity in design and composition of both domes are regarded as one of uniform characteristics the Timurid architecture (fig. 4. 21a). Morphologically, its load bearing system consisted of various types of projected and blind arches which were configured symmetrically (fig. 4.21c). Its transition tier chiefly was shaped by complicated *muqarnas* rows (fig. 4.21b).

The internal shell shape is semi-elliptical (fig.4.21k) while the externals shell has pointed formation with fluted surface that showed specific development in the construction techniques (fig. 4.21); the thicknesses of both shells gradually reduced from the base to the top of the dome. The height of drum compared to the overall proportion of building is also very high and vast.

The internal stiffeners presented the specific development in composition and arrangements (fig. 4.22). They consisted of eight radial brick walls (fig. 4.21e) which their thicknesses are gradually reduced in the upper parts (fig. 4.21d). There exist two types of wooden struts with different arrangements which articulated those radial walls in regular distances (fig. 4.21). On the typological point of view, this sample dome composition presented the specific development in the design and using diverse components and vocabularies that ranked it into the compound typology with drum.

Results of geometrical analysis suggest a four-centered profile with the following geometrical characteristics which can be arranged according to the proposed parametric system (fig. 4.21 f):

- External shell: $\left\{\begin{bmatrix} 2/6ab \\ 0 \end{bmatrix}, \angle 45, \begin{bmatrix} ab \\ 2/6ab \end{bmatrix}\right\}$

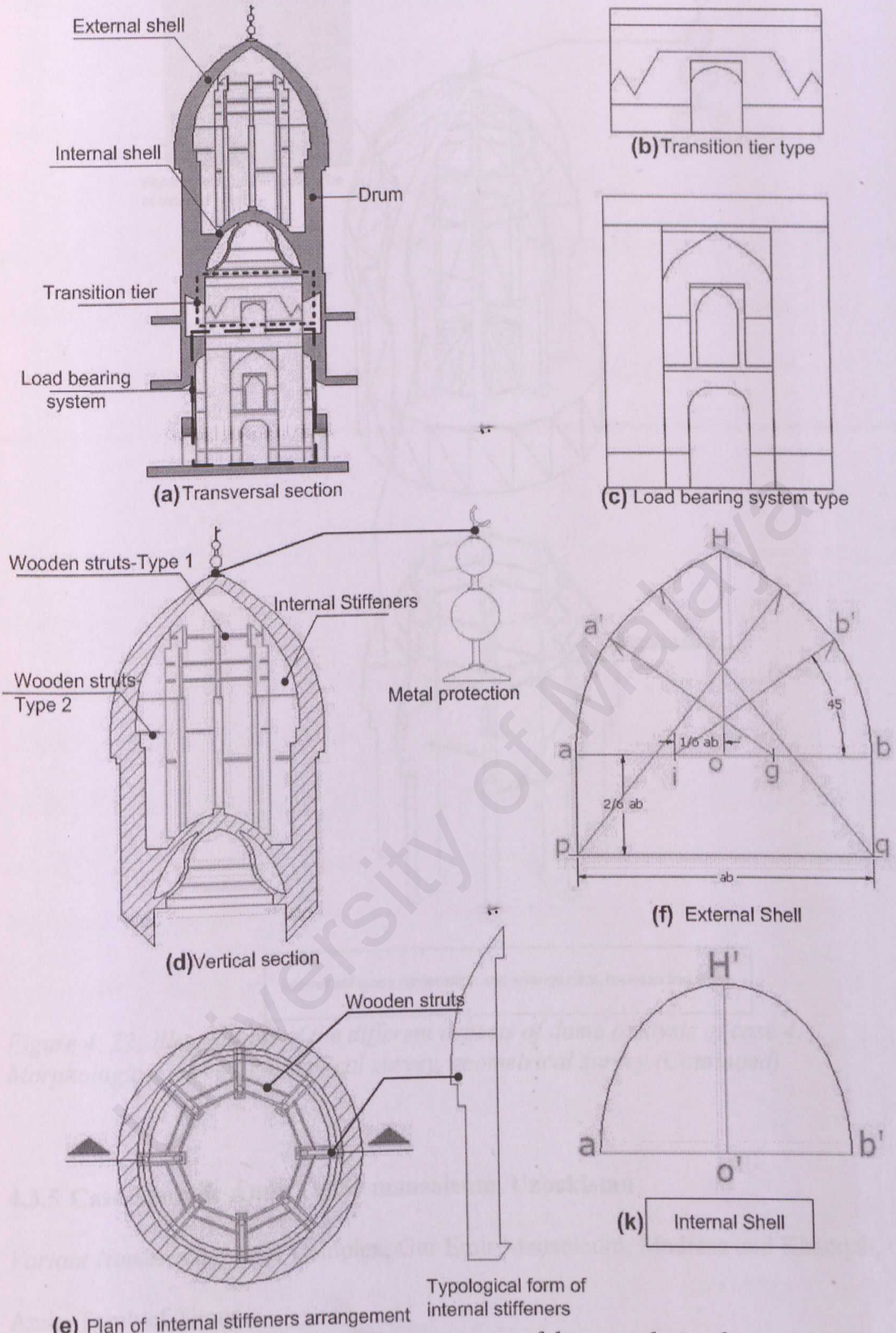


Figure 4. 21: Illustrations of the different aspects of dome analysis of case 4: Morphological survey, typological survey, geometrical survey.

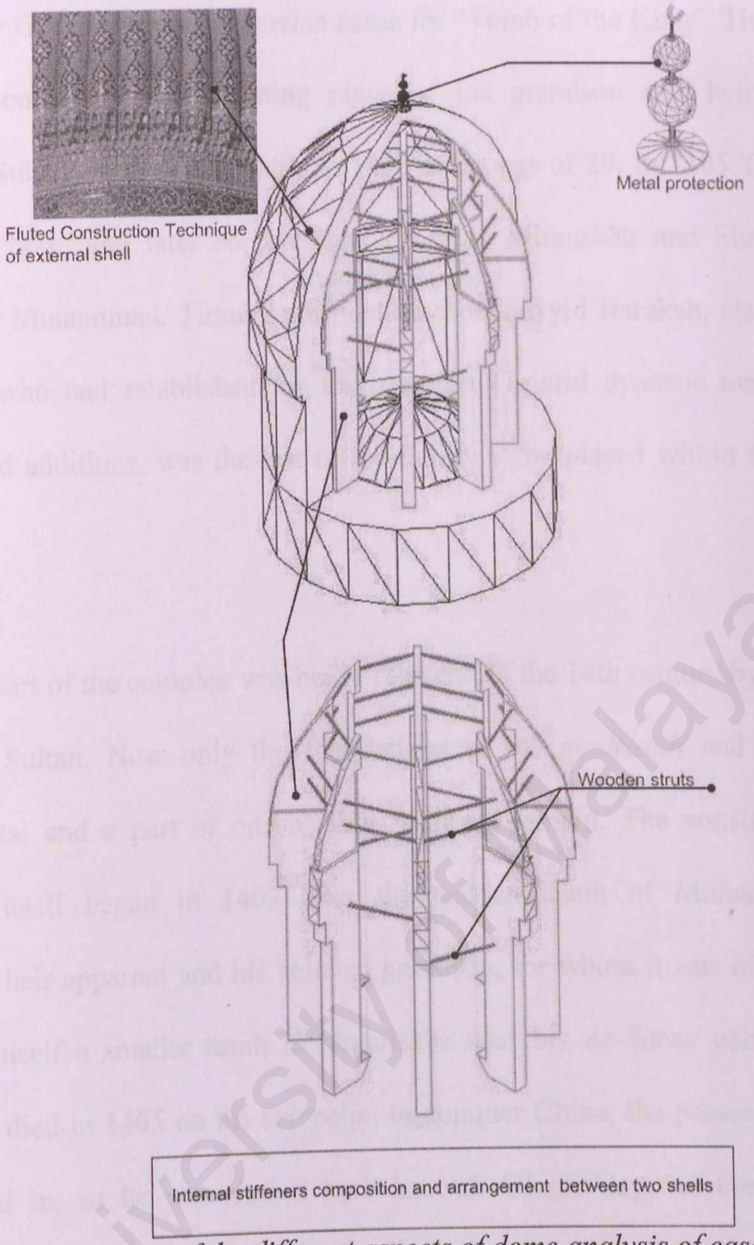


Figure 4. 22: Illustrations of the different aspects of dome analysis of case 4: Morphological survey, typological survey, geometrical survey (Continued).

4.3.5 Case Study 5: Amir Timur mausoleum, Uzbekistan

Variant Names: Gur Amir Complex, Gur Emir Mausoleum, Madrasa and Khanqah, Gur Amir, Tomb of Timur

Location: Samarkand, Uzbekistan

Date/Period: 1403-1404 A.D./ 15th Century

Building Types: educational, funerary

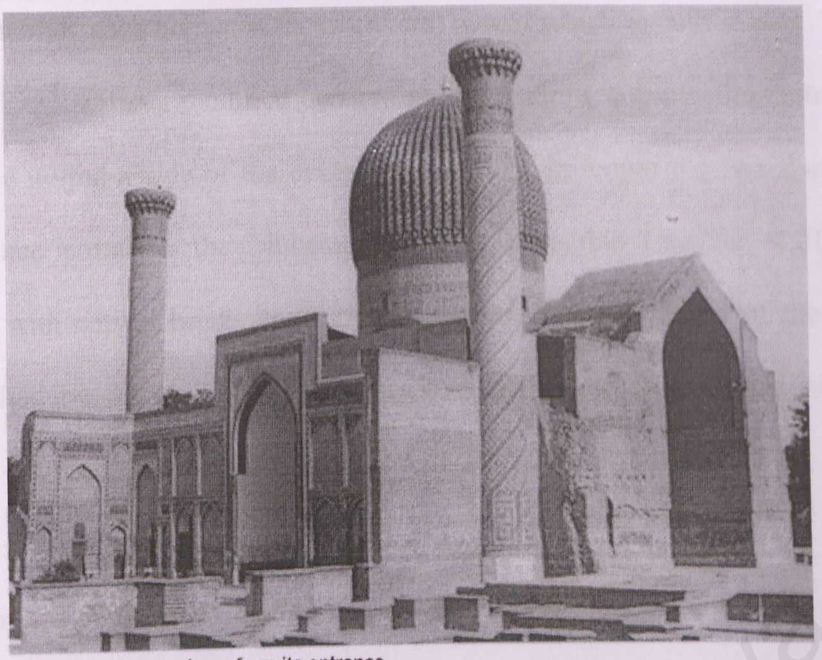
Building Usage: madrasa, mausoleum

i. History: Gur-e Amir is the Persian name for "Tomb of the King". Timur built this celebrated monument as the resting place of his grandson and heir-presumptive Muhammad Sultan, who died in battle in 1403 at the age of 29. In 1405 Timur himself was interred here, and later so too were his sons Miranshah and Shah Rukh and grandson, Pir Muhammad. Timur's spiritual advisor, Sayyid Barakah, also lies within. Ulugh Beg, who had established the tomb as the Timurid dynastic mausoleum and commissioned additions, was the last of the family to be placed within the crypt (fig. 4.23).

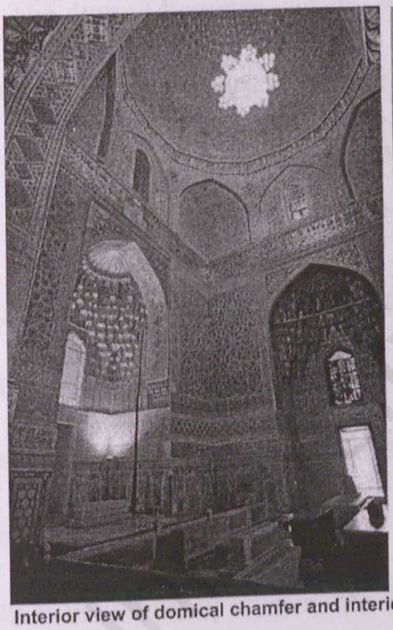
The earliest part of the complex was built at the end of the 14th century by the orders of Muhammad Sultan. Now only the foundations of the *madrasah* and *khanaka*, the entrance portal and a part of one of four minarets remain. The construction of the mausoleum itself began in 1403 after the sudden death of Muhammad Sultan, Tamerlane's heir apparent and his beloved grandson, for whom it was intended. Timur had built himself a smaller tomb in Shahrisabz near his *Ak-Saray* palace. However, when Timur died in 1405 on his campaign to conquer China, the passes to Shahrisabz were snowed in, so he was buried here instead. Ulugh Beg, another grandson of Tamerlane, completed the work. During his reign the mausoleum became the family crypt of the Timurid Dynasty (Blair and Bloom, 1994).

In 1740, the Persian warlord Nadir Shah stole the stone, but it broke in two and he started to have a run of extremely bad luck. His advisors urged that he return the stone to its rightful place immediately. The second time the stone was disturbed was on June 19, 1941 when Soviet archaeologists opened the crypt. The anthropologist Mikhail Gerasimov was able to reconstruct Tamerlane's facial features from his skull, and it was also confirmed that he was a giant for his day, was 172 cm tall, and would have walked with a pronounced limp (Golombek and Wilber, 1988).

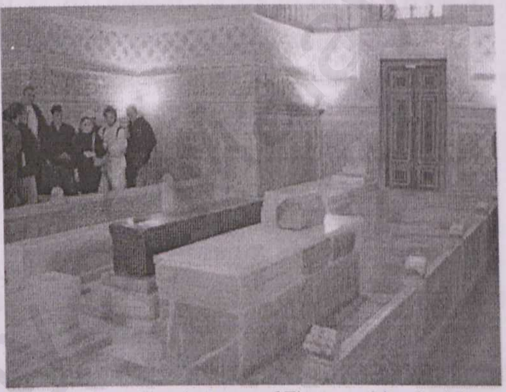
Further historical information about the assassination of Ulugh Beg and the authenticity of the other graves was also confirmed. However, the archaeologists involved also invoked the curse, as the Nazis invaded Russia three days later. The tomb inscription reads: "Anyone who violates my stillness in this life or in the next one, will be subjected to inevitable punishment and misery". Timur's skeleton and that of Ulugh Beg, his grandson, were reinterred with full Islamic burial rites in 1942, on the same day as the victory in Stalingrad (Golombek and Wilber, 1988).



Main view of mausoleum from its entrance



Interior view of domical chamfer and interior shell



Interior view of tombstones of Timur, spiritual advisor, and his sons.

Figure 4. 23: Illustration of exterior and interior views of the dome and its chamber (Sources: www.picasaweb.google.com/lh/photo/UUW2e8k-M6G_QQBW2P6eNA; www.advantour.com/uzbekistan/samarkand/gur-emir.htm).

ii. Architecture: The mausoleum was constructed on the Southern side of a walled square courtyard already defined on two sides by a *madrasa* and *khanaqah*, no longer extant. Outwardly the Gur-e Amir Mausoleum is a one-cupola building. It is famous for its simplicity of construction and for its solemn monumentality of appearance. It is an octahedral building crowned by cerulean fluted dome (*see* fig.4.23, exterior view) (Michell, 1995; Hillenbrand, 1994).

Minarets marked each corner of the courtyard, two of which remain in part. The plan of the mausoleum forms a modified octagon on the exterior: a projecting entrance portal extends the northern side of the octagon, decreasing in length the two flanking sides. The entrance portal to the Muhammad Sultan ensemble (*see* fig. 4.21) is richly decorated with carved bricks and various mosaics. The decoration of the portal was accomplished by the skilled craftsman (*ustad* in Persian) Muhammad bin Mahmud Isfahani.

A fluted ribbed dome on a tight high drum presents a monumental profile visible across the city. The dome (diameter - 15 m (49.21 ft), height - 12.5 m (41.01 ft) is of a bright blue color with deep rosettes and white spots. Heavy ribbed fluting imparts an amazing expressiveness to the cupola (Golombek and Wilber, 1988; Hillenbrand, 1994).

The interior comprises a square chamber, a bay on each wall, a stairway in the southeast corner leading to the cruciform crypt, an octagonal zone of transition and an unusually steep hemispheric dome (fig. 4.24 central plan). Vertical flanges linked with timber are concealed between the two shells of the dome, supported by the internal shell and providing structure for its external shell; an invisible "column" built on top of the center point of the internal shell terminates in angled timber prongs that also support the outer dome (Golombek and Wilber, 1988; Hillenbrand, 1994).

In 1424 Ulugh Beg added a corridor known as his "gallery", entered through the eastern bay of the mausoleum. Four vaulted bays form the corridor lead to a small vestibule accessed from the courtyard. In the seventeenth century construction of an *iwan* on the western side of the mausoleum commenced, but remained unfinished.

The exceptional interior decorative scheme employs luxurious materials and a wealth of techniques. Onyx hexagons form a dado, capped by a shallow cornice of marble *muqarnas*. Above this, a gold inscription band painted onto jasper encircles the mausoleum. Constituting one of the earliest examples of this technique, papier-mache was employed extensively; the internal shell, the zone of transition and the *muqarnas* vaults of the four bays of its internal shell were all decorated with painted molded papeir-mache. Other areas were plastered and painted, or covered with a revetment of various materials.

The exterior decoration employs extensive *hazarbaf* brickwork. The exterior decorations of the walls consist of blue, light-blue and white tiles organized into geometrical and epigraphic ornaments against a background of terracotta bricks. The dome is tiled in two tones of blue. Bands of tile inscriptions encircle the drum; a monumental kufic inscription of white and black tiles repeats "Allah is eternal" (Michell, 1995).

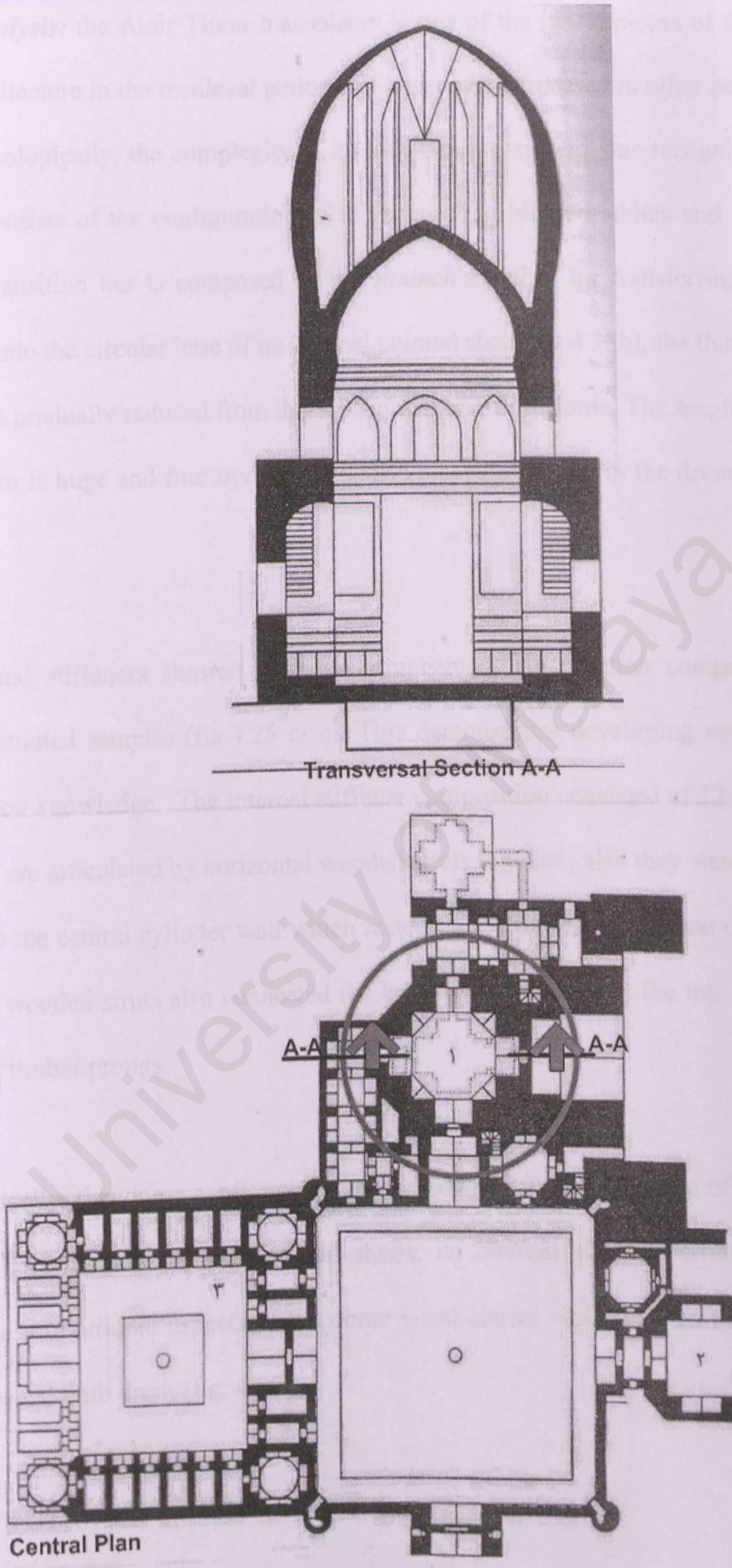


Figure 4. 24: Various architectural drawings of case 5 (Golombek and Wilber, 1988; Hillenbrand, 1994).

iii. Analysis: the Amir Timur mausoleum is one of the masterpieces of the Islamic dome architecture in the medieval period that was never surpassed in other periods later on. Morphologically, the complexity in its load bearing system was recognized (fig.4. 25c). It consists of the configuration of the supporting blinded arches and walls. The zone of transition tier is composed of the *squinch*'s niches for transferring from the rectangle into the circular base of its internal pointed shell (fig.4.25b); the thicknesses of both shells gradually reduced from the base to the top of the dome. The height and scale of the drum is huge and four opening windows placed regularly in the drum body (fig. 4.25a).

The internal stiffeners showed different arrangement composition compared to the previous studied samples (fig.4.25 d, e). This demonstrates developing structural and construction knowledge. The internal stiffener composition consisted of 12 brick radial walls that are articulated by horizontal wooden struts together; also they were connected entirely to the central cylinder wall which rested on the internal shell apse (fig.4.26). A series of wooden struts also connected the brick cylinder drum to the top of the dome by angled timber prongs.

Grammatically, this dome configuration presented special developments of geometrical concepts in both internal and external shells, its internal stiffener arrangement and finally the proportional aspects of the dome vocabularies which ranked this sample as the compound with drum (fig. 4.25a).

From the geometrical point of view, using general profile analysis, two types of two-centered and four-centered profiles with the different geometrical characteristics were recognized for both the internal and external shells which can be formulated according to proposed parametric system (fig. 4.25, f, k):

- External shell: $\left\{\begin{bmatrix} 2/8ab \\ 0 \end{bmatrix}, 0, \begin{bmatrix} 0 \\ 0 \end{bmatrix}\right\}$; and
- Internal shell: $\left\{\begin{bmatrix} 2/10ab \\ 0 \end{bmatrix}, \angle 30, \begin{bmatrix} 8/10ab \\ 3/10ab \end{bmatrix}\right\}$.

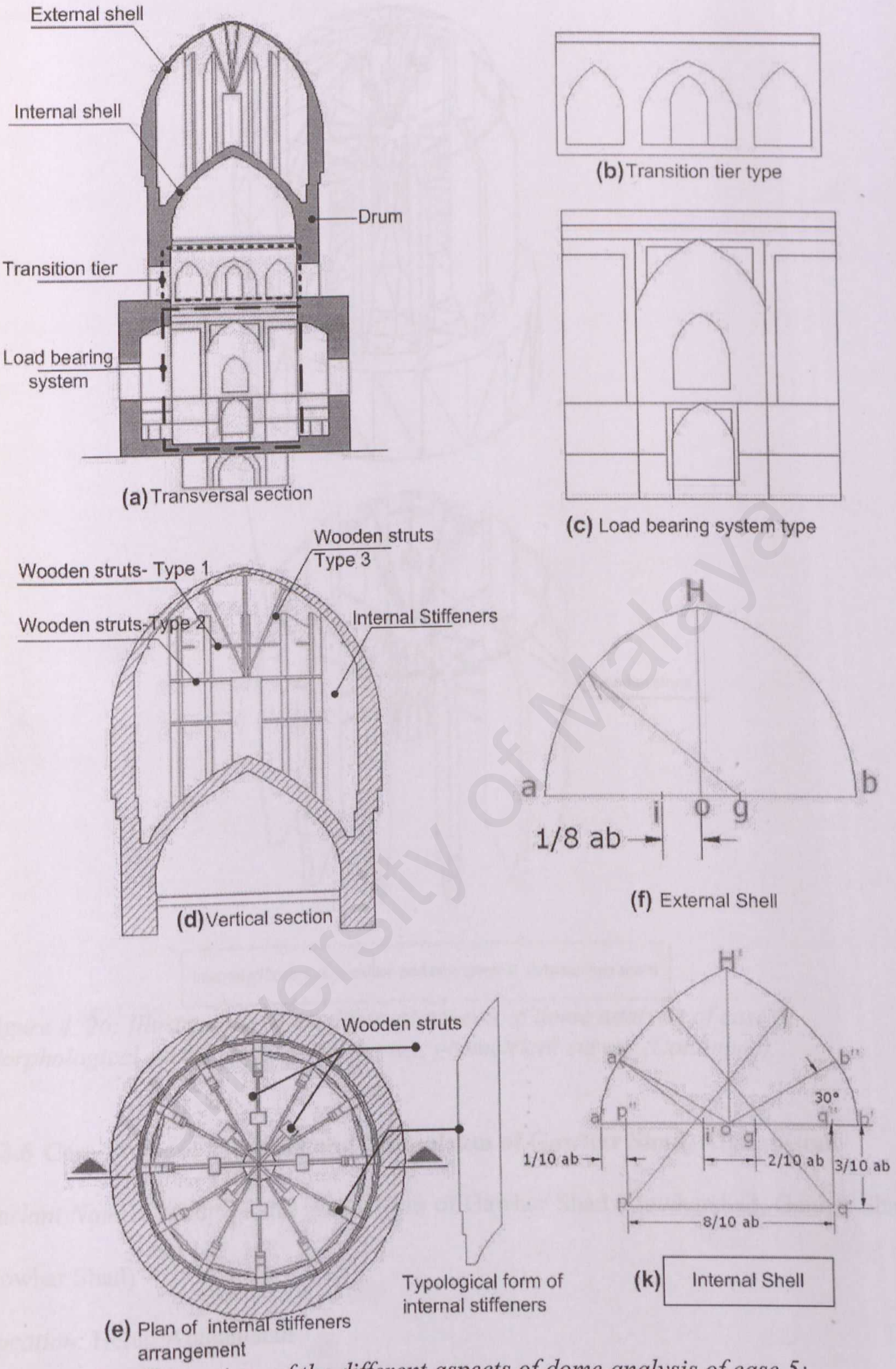


Figure 4. 25: Illustrations of the different aspects of dome analysis of case 5: Morphological survey, typological survey, geometrical survey.

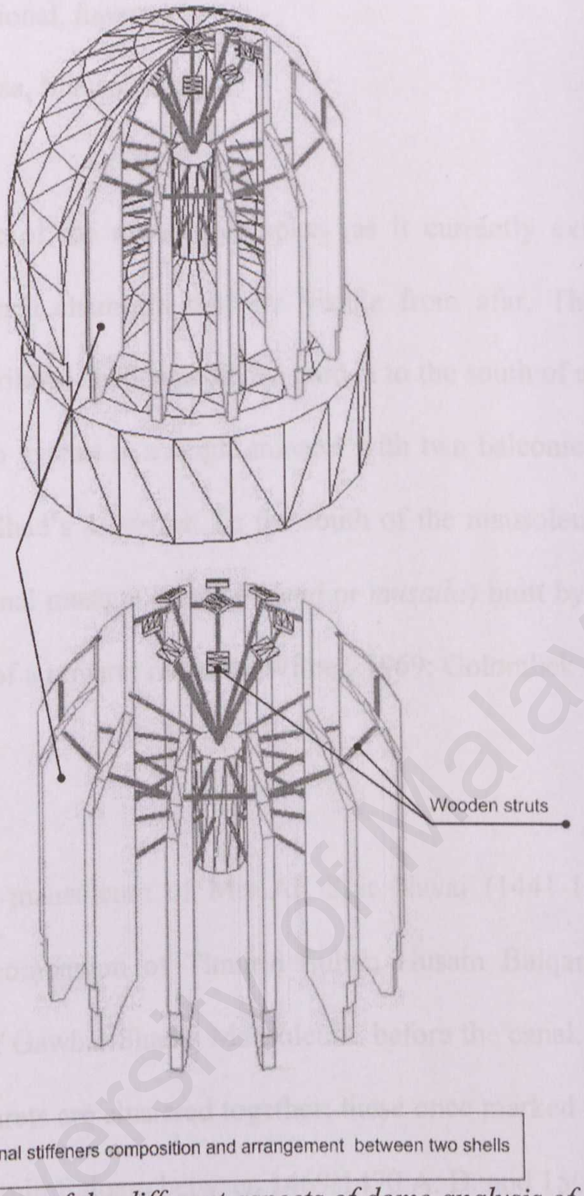


Figure 4. 26: Illustrations of the different aspects of dome analysis of case 5: Morphological survey, typological survey, geometrical survey (Continued).

4.3.6 Case Study 6: Madrasa and Mausoleum of Gawhar Shad, Afghanistan

Variant Names: Madrasa and Mausoleum of Gawhar Shad (Gawharshad, Gauhar Shad, Gowhar Shad)

Location: Herat, Afghanistan

Architect/Planner: Qavam al-Din Shirazi

Client: Gawhar Shad

Date: 1417-1438 A.D.

Style/Period: Timurid/ 15th Century

Building Types: Educational, funerary

Building Usage: Madrasa, Mausoleum

i. History: The site of the *musalla* complex (as it currently exists) contains six minarets and two domed chambers that are visible from afar. The Mausoleum of Gawhar Shad, with its ribbed shell, stands in a garden to the south of an irrigation canal that bisects the site. To its east is a single minaret with two balconies; it once flanked the portal of Gawhar Shad's *Madrasa*. To the south of the mausoleum was a place of worship, a congregational mosque (*masjid-i jami* or *musalla*) built by Gawhar Shad, of which only the stump of a minaret remains (Wilber, 1969; Golombek and Wilber, 1988; fig. 2.27).

Smaller dome of the mausoleum of Mir Ali Shir Navai (1441-1501), who was a prominent poet and companion of Timurid Sultan Husain Baiqara (1469-1506), is located to the North of Gawhar Shad's Mausoleum, before the canal. In the plain North of the canal, four minarets are clustered together; these once marked the four corners of a *madrasa* built by Husain Baiqara between 1469/1470 A. D. and 1506 A.D.

The *musalla* complex, which designed and built (1417 A.D.) under Queen Gawhar Shad's artistic direction, has been described as "the most beautiful example in color in architecture ever devised by man to the glory of his God and himself".

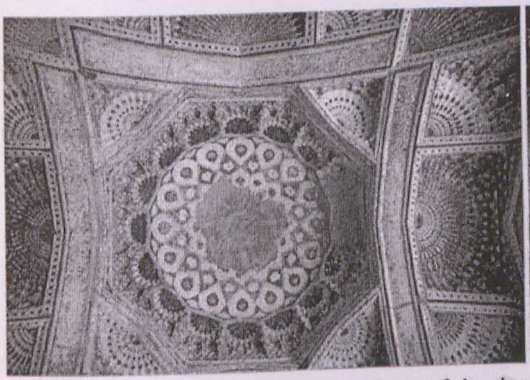
Only three examples remained and most of the buildings in this complex were purposely demolished under the direction of British troops in 1885 when a Russian attack on Herat was feared. The attack never materialized but these great works of art were irretrievably lost (Wilber, 1969; Golombek and Wilber, 1988).

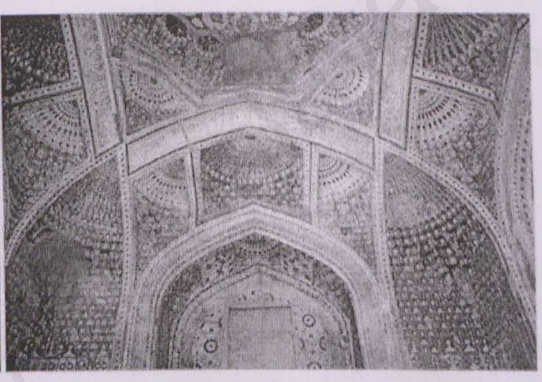
Only the minarets and the Mausoleum of Gawhar Shad were allowed to remain. Two of the mosque's four minarets were destroyed in an earthquake in 1932, and only one survives today. The Society for the Preservation of Afghanistan's Cultural Heritage (SPACH) completed emergency conservation works on the site in 2001, including building protective walls around the Gawhar Shad Mausoleum and Sultan Husain *Madrasa*, repairing the remaining minaret of Gawhar Shad's *Madrasa*, and replanting this mausoleum garden (Memarian, 1988).

Gawhar Shad's son Baysunghur was buried in this mausoleum a year after its completion. Seven additional Timurid princes, as well as Gawhar Shad, are believed to have been buried here; Russian agent Nicholas de Khanikoff reported seeing Gawhar Shad's tombstone when he visited the site sometime before 1860; her tombstone is currently missing. Gawhar Shad was murdered in 1457 (Wilber, 1969; Golombek, 1988).

Main view of mausoleum from its entrance

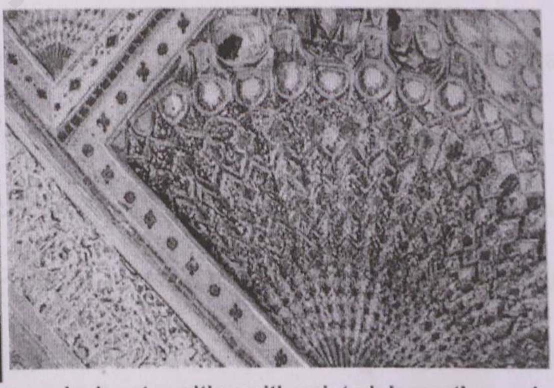
View of typical connection domical ribs by *muqarnas* combs





Interior views of domical chamfer and interior shell

showing section of squinch-net vaulting with painted decoration



squinch-net vaulting with painted decoration and *muqarnas*

Figure 4. 27: Illustration of exterior and interior views of the dome and its chamber (Sources: The Afghanistan Ministry of Culture & Youth Affairs; www.archnet.org; Website of Society for the Preservation of Afghanistan's Cultural Heritage (SPACH).

ii. Architecture: It was completed in 1432 A.D. The mausoleum of Gawhar Shad was located in the westernmost corner of the Gawhar Shad *Madrasa* and now stands alone. The chamber has a cruciform plan (nine and a half meters on each side) with a five-sided *qibla* bay projecting Southwest (fig.4.28). Four arched niches occupy the recesses and are inscribed in four grand arches intersecting at the corners of the dome chamber (fig.4.27, views from dome chamber).

Squinches provide the transition from the four corners to an eight-pointed star, followed by an octagon and a sixteen-pointed star that circle in towards the thirty-two sided star at the vault's apex. This intricate *squinch*es vault is richly decorated with painted floral motifs and inscriptions highlighted with gold (Golombek and Wilber, 1988).

Gawhar Shad's mausoleum is topped by "gadrooned" dome (Yaghan, 2003) of Persian-blue, set above a high drum encircled with a dazzling white Quranic inscription against a royal-blue background. Tall panes bejeweled with floral decorations enriched its richness of decorations. The interior is equally rich with painted and architectural ornamentation: a profusion of interfacing arches, fan-shaped *squinches*, stalactite niches, small and large domes, are delicately adorned with bands of calligraphy and all manner of decorations represented the privilege of vernacular architecture. The blue pigment used in this painting was made from crushed lapis lazuli from *badkhshan*. In the center are tombstones of the Queen, her son Baisunghur and various grandsons and great-grandsons (Petersen, 1996).

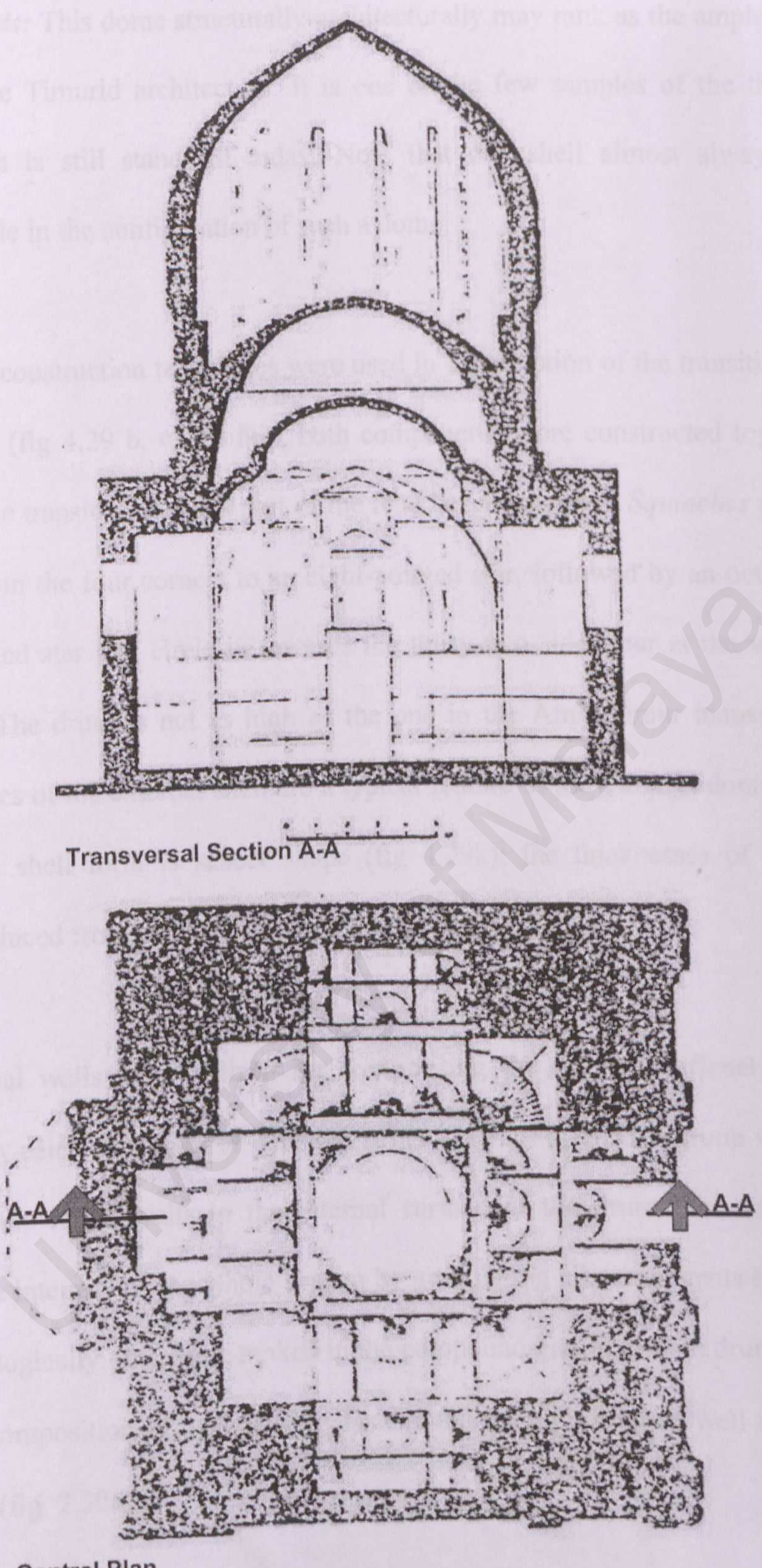


Figure 4. 28: Various architectural drawings of case 6 (Golombek and Wilber, 1988; Memarian, 1988).

iii. Analysis: This dome structurally-architecturally may rank as the ample remained sample of the Timurid architecture. It is one of the few samples of the three shells domes which is still stand till today. Note that one shell almost always plays a decorative role in the configuration of such a dome.

The specific construction techniques were used in construction of the transition tier and load bearing (fig 4.29 b, c). In fact, both components were constructed together as a whole and the transition tier is a part of the load bearing system. *Squinches* provide the transition from the four corners to an eight-pointed star, followed by an octagon and a sixteen-pointed star that circle in towards the thirty-two sided star at the vault's apex (fig.4.29b). The drum is not as high as the one in the Amir Timur mausoleum. The fluted surfaces of the external shell are a typical feature of the Timurid dome buildings. The internal shell form is saucer shape (fig 4.29k); the thicknesses of both shells gradually reduced from the base to the top of the dome.).

The 12 radial walls were utilized for compositing the internal stiffeners. They are connected by using two types of wooden struts (fig.4.29 d, e). One group was used for connecting the radial walls to the internal surface of the drum. The second group provided the integrity of the whole system by articulating all components together (fig. 4.30). Typologically, this dome ranked in the compound grammar with drum because of its special composition of load bearing system and transition tier as well as the use of three shells (fig. 2.30a).

Geometrical analysis showed a four-centered profile with the following geometrical parameters of its external shell; it can be formulated according to the proposed parametric system as follows (fig. 4.29, f):

- External shell: $\left\{\begin{bmatrix} 2/8ab \\ 0 \end{bmatrix}, \angle 30, \begin{bmatrix} 6/8ab \\ 7/16ab \end{bmatrix}\right\}$

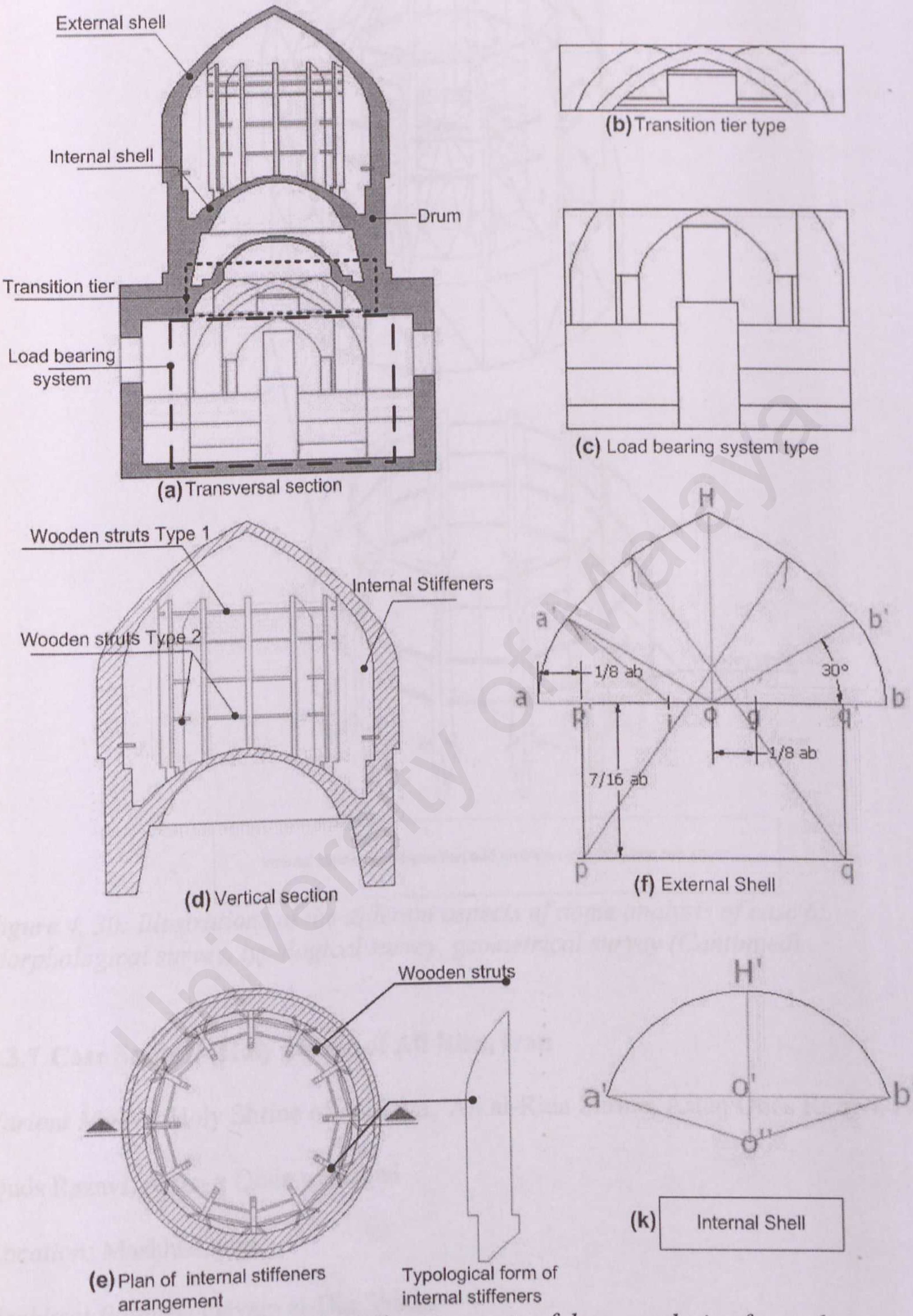


Figure 4. 29: Illustrations of the different aspects of dome analysis of case 6: Morphological survey, typological survey, geometrical survey.

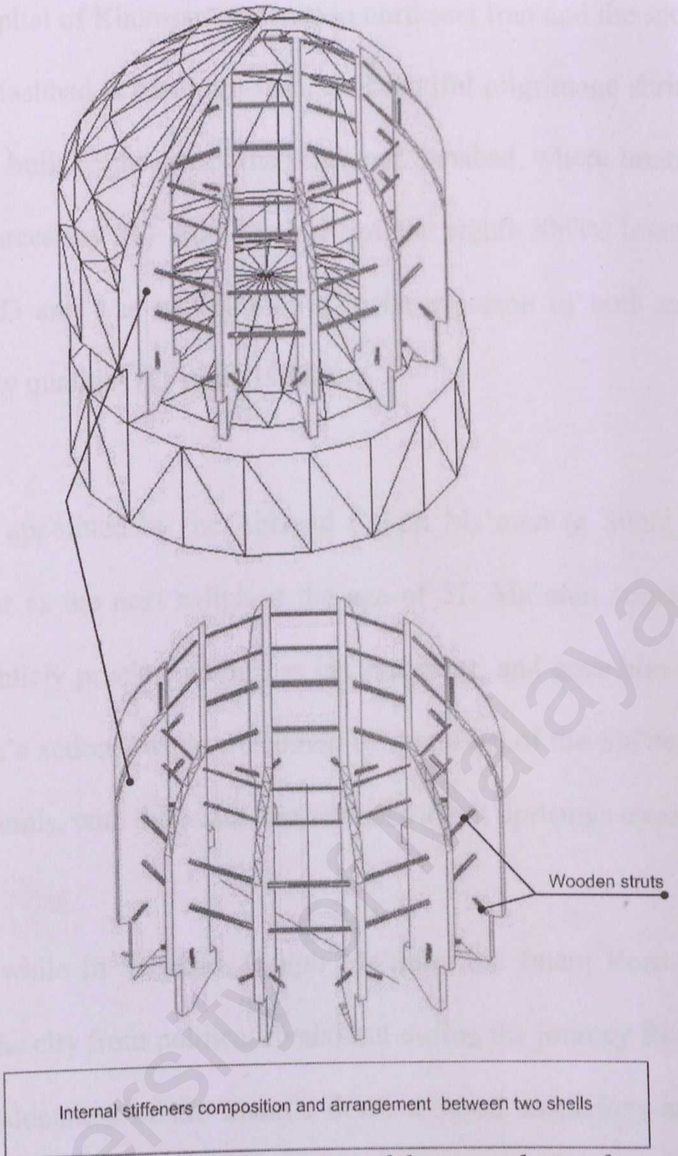


Figure 4. 30: Illustrations of the different aspects of dome analysis of case 6: Morphological survey, typological survey, geometrical survey (Continued).

4.3.7 Case Study 7: Holy Shrine of Ali Riza, Iran

Variant Names: Holy Shrine of Ali Riza, 'Ali al-Rida Shrine, Astan Qods Razavi, Astan Quds Razavi, Astan-e Qods-e Razawi

Location: Mashhad, Iran

Architect/Planner: Qavam al-Din Shirazi

Date: 1400-2000 A.D.

Style/Period: Timurid/ 14th Century

Building Types: Funerary, religious

Building Usage: Tomb, shrine

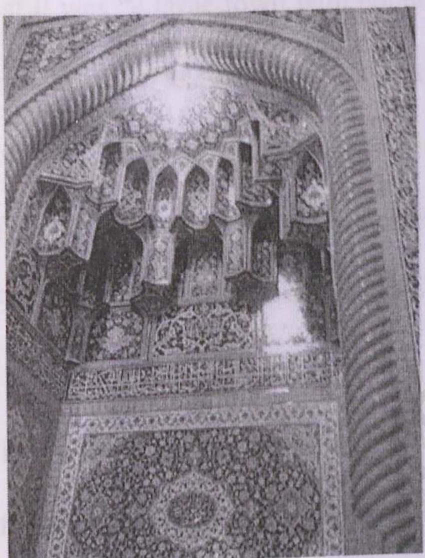
i. History: The capital of Khorasan province in northeast Iran and the second largest city in the country, Mashhad is best known for its beautiful pilgrimage shrine of Imam Reza. The shrine was built on the site of the village of Sanabad, where Imam Reza died in 818 AD (some sources say 817 AD). Imam Reza, the eighth Shi'ite Imam, was born in Medina in 765 AD and was widely known to be a person of both extraordinary scholarship and saintly qualities (O'kane, 1987).

He was surprisingly appointed by the Abbasid Caliph Ma'mun (a Sunni Muslim) to become his successor as the next caliph at the age of 51. Ma'mun summoned Imam Reza to Sanabad, publicly proclaimed him as his successor, and gave him his daughter in marriage. Ma'mun's actions, while welcomed by members of the Shi'ite sect, deeply disturbed the rival Sunnis, with the result that several violent uprisings ensued.

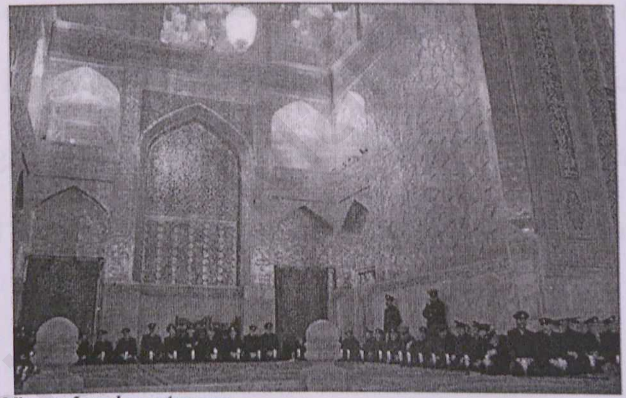
After staying for a while in Sanabad, Caliph Ma'mun and Imam Reza departed for Baghdad (to retake the city from political rivals) but during the journey Reza fell ill and rapidly died. The suddenness of the Imam's death aroused suspicions among Shi'ite believers who believed Ma'mun had poisoned him in order to quell the political unrest resulting from a Shi'ite Imam being proclaimed caliph-to-be of the vastly more numerous Sunni believers.

The Caliph, however, showed sings of deep mourning and built a mausoleum over the Imam's grave in 818 AD, adjacent to his own father's tomb. Because of the widespread Shi'ite belief that Ma'mun had murdered Reza, the tomb and the village of Sanabad were given the name of Mashhad ar-Rizawi, meaning "the place of the martyrdom of Riza" (fig. 4. 31).

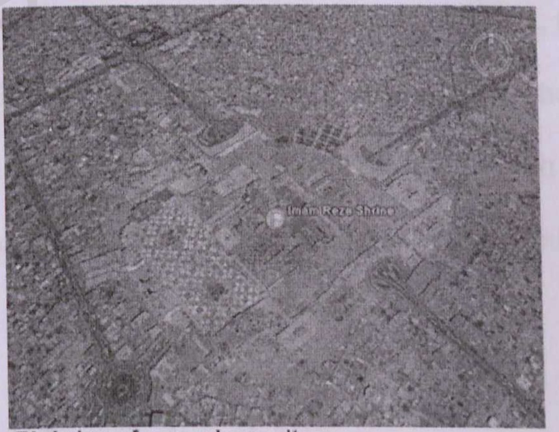
Main view of mausoleum from its *iwan*



View of *mihrab*



View of main entrance



Bird view of mausoleum site

Figure 4. 31: Illustration of exterior, interior views and bird's eye view of the dome and its chamber (Sources: www. beautiesofiran.com/RazaviKhorasan.html; www.archnet.org).

***ii. Architecture*:** The original mausoleum over Imam Reza's tomb was destroyed by Sabuktagin, the Ghaznevid sultan in 993AD but was rebuilt and extensively enlarged by his son Mahmud of Ghazni in 1009AD. During this time the shrine was ornamented with tiles, some of which are still visible in the innermost dome chamber. In 1220AD, the Mongols plundered the city and shrine. A century later the Mongol ruler of Iran, Sultan Muhammad Khudabandeh converted to Shi'ism, and during his reign (1304-1316AD) again renovated the shrine on a grand scale (Pope, 1971).

The celebrated Moorish traveler Ibn Battuta visited Mashhad in 1333 A.D. and reported that it was "a large town with abundant fruit trees, streams and mills (O'kane, 1987). A great dome of elegant construction surmounts on this noble mausoleum with the rich colored tiles decorated its walls" (fig. 4.32). Opposite the tomb of the Imam is the tomb of Caliph Harun al-Rashid, which is topped by a platform bearing chandeliers (O'kane, 1987).

The most glorious phase of Mashhad began during the reign of Shahrukh Mirza, the son of Tamerlane, and reached its zenith during the reign of the Safavid kings who ruled Iran from 1501 to 1786. The Safavid kings beautified the religious complex with golden domes, tiled minarets and spacious courtyards as well as extensive academic buildings (Blair and Bloom, 1994).

Having established Shi'ism as the state religion, the brilliant early Safavid rulers, Shah Ismail I, Shah Tahmasp and particularly Shah Abbas I strongly encouraged pilgrimage to the shrine of Imam Reza, as well as to the shrine of his sister Fatima in the holy city of Qum. Nadir Shah Afshar and the Qajar kings who ruled Iran from 1779-1923 further enlarged and ornamented the shrine complex, though this period also saw the occasional raids of warlike Turks, Uzbeks and Afghans. The shrine was shelled by Russian artillery in 1912 and further damaged by troops of Reza Khan in 1935 and Reza Shah in 1978. Since that time the shrine has undergone near continuous renovation and enlargement, and currently over 20 million (Golombek, 1988) pilgrims visit the tomb of Imam Reza (Stevens, 1979).

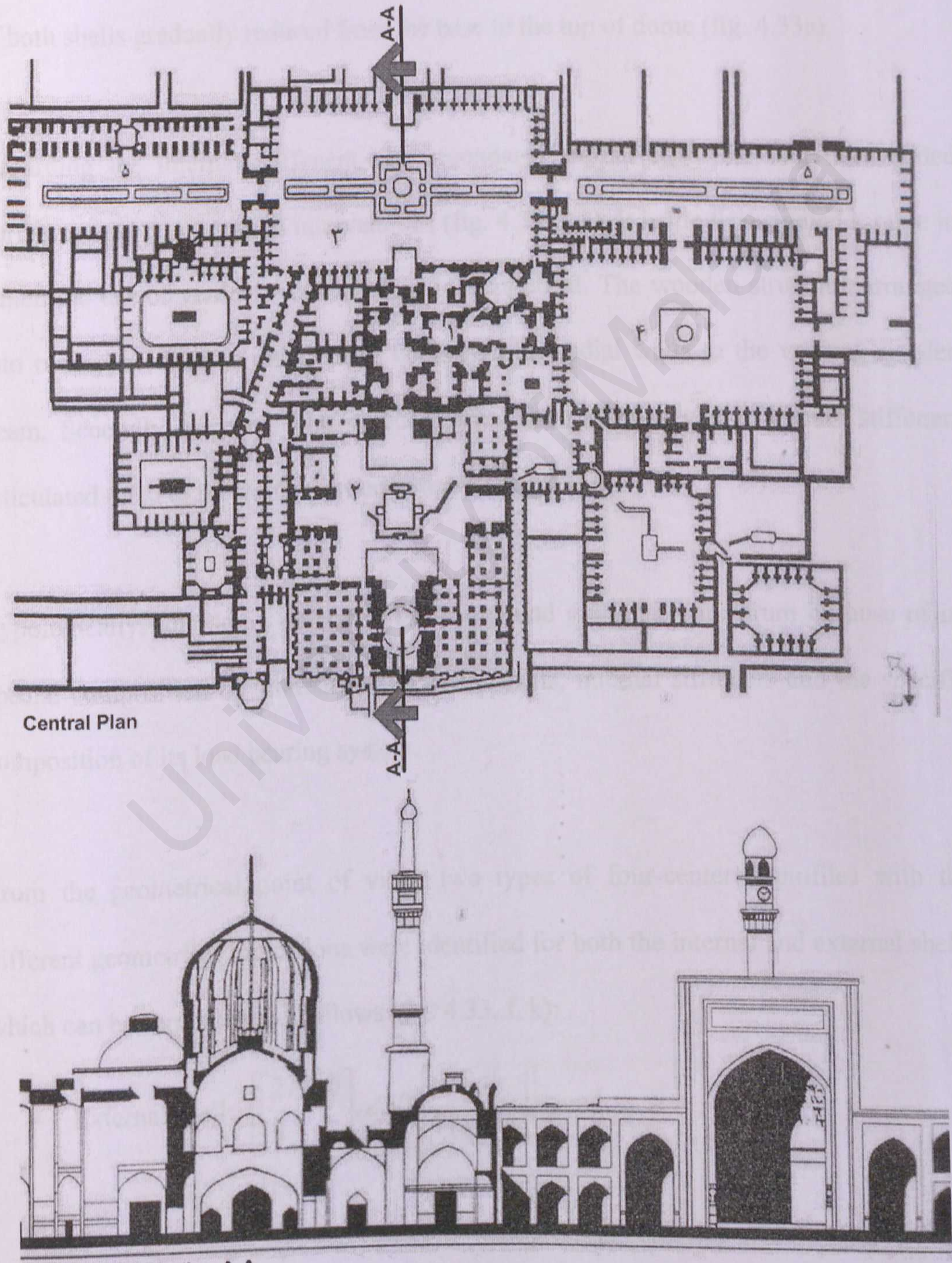


Figure 4.32: Various architectural drawings of case 7 (Pirniya and Bozorgmehri, 1992).

iii. Analysis: The dome, conceptually, is a second populist style of dome in the greater Khorasan[8] during the Timurid dynasty. This dome had, however, been conserved over various eras. From the morphological point of view, the load bearing system is composed of the huge arched systems (fig. 4.30c). The transition tier is a typical row of high blinded niches with rectangular frames surrounding them (fig. 4.30b). Its internal shell shape is the shallow pointed in such a way that their thicknesses of both shells gradually reduced from the base to the top of dome (fig. 4.33a).

Regarding the internal stiffeners, the secondary internal stiffeners had been added during several conservation interventions (fig. 4.33 d, e). It is the first studied sample in which the use of vertical wooden beam is recognized. The wooden struts are arranged into two types. Firstly, radial struts connected the radial walls to the vertical wooden beam. Secondly, perpendicular wooden struts are set out between 8 main stiffeners articulated them to the vertical wooden beam (fig. 4.34).

Typologically, this dome ranked in the compound grammar with drum because of its special composition of internal and external shells, internal stiffeners and the specific composition of its load bearing system.

From the geometrical point of view, two types of four-centered profiles with the different geometrical indications were identified for both the internal and external shells which can be formulated as follows (fig. 4.33, f, k):

- External shell: $\left\{\begin{bmatrix} 2/8ab \\ 0 \end{bmatrix}, \angle 30, \begin{bmatrix} 6/8ab \\ 7/16ab \end{bmatrix}\right\}$; and

[8] **Greater Khorasan** (Persian: خراسان بزرگ) (also written *Khorasaan*, *Khurasan* and *Khurasaan*) is a modern term for a geographic region spanning (in clockwise order) north-eastern Iran, Turkmenistan, Uzbekistan, Tajikistan and north-western Afghanistan. The name "Khorasan" is said to derive from Middle Persian.

- Internal shell: $\left\{\begin{bmatrix}2/10ab\\0\end{bmatrix},\angle 30,\begin{bmatrix}4/10ab\\4/10ab\end{bmatrix}\right\}$

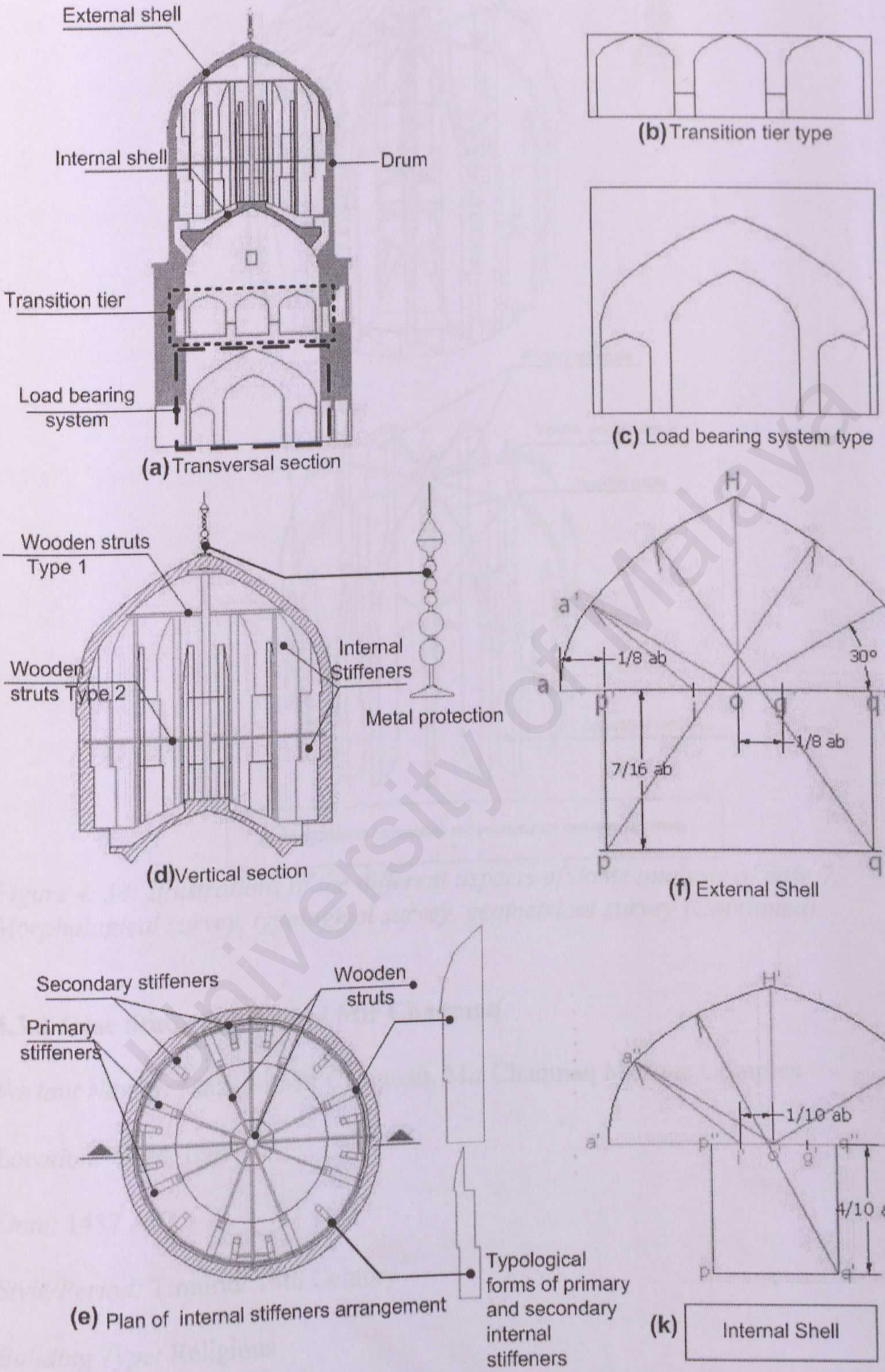


Figure 4. 33: Illustrations of the different aspects of dome analysis of case 7: Morphological survey, typological survey, geometrical survey.

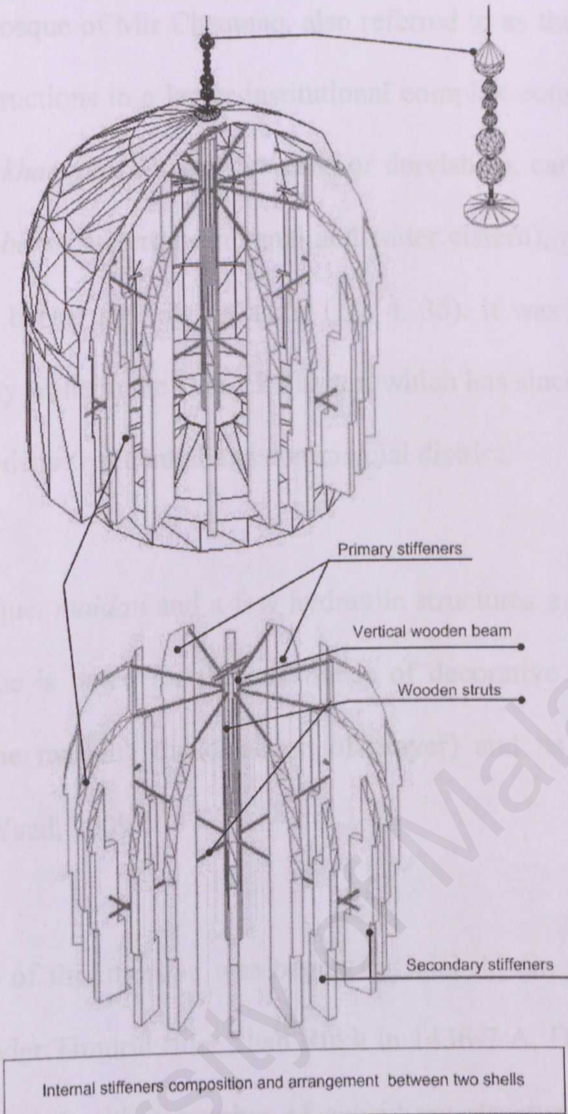


Figure 4. 34: Illustrations of the different aspects of dome analysis of case 7: Morphological survey, typological survey, geometrical survey (Continued).

4.3.8 Case Study 8: Masjid-i Mir Chaqmaq

Variant Names: Masjid-i Mir Chaqmaq, Mir Chaqmaq Mosque Complex

Location: Yazd, Iran

Date: 1437 A.D.

Style/Period: Timurid/ 15th Century

Building Type: Religious

Building Usage: Mosque

i .History: The mosque of Mir Chaqmaq, also referred to as the Masjid-e Nau, was one of the first constructions in a larger institutional complex consisting of a *madrasa* (theological school), *khanqah* (a hostel for sufis or dervishes), caravanserai (traveler's inn), *qanat* and *abanbars* (subterranean canal and water cistern), public baths, *maidan* or public square and bazaar sharing the name (fig. 4. 35). It was built outside Yazd's fourteenth century city walls in the Dehkok quarter, which has since transformed from a suburban garden to a dense residential and commercial district.

Today only the mosque, *maidan* and a few hydraulic structures exist from the original complex. The mosque is noted for the excellence of decorative craftsmanship on its marble *mihrab* (niche marking the direction of prayer) and its portal's tile mosaic calligraphic panels (Yazd, 2009).

In fact, construction of this mosque was begun by Jalal Al-din Chaqmaq Shami, the governor of Yazd under Timurid ruler Shah Rukh in 1436-7 A. D., and was completed some years later, aligned with a number of subsidiary structures through the active patronage of Bibi Fatima Khatun, wife of Mir Chaqmaq. In addition to the Masjid-i Jami or congregational mosque of Yazd by the same patrons, the Masjid-i Mir Chaqmaq was erected in the period of great economic prosperity.

Large urban design projects were ordered after the Timur's conquest in 1393 A.D., funded by revenues made possible by the Timurid policy of retaining the Muzaffarid provincial capital of Kerman, Fars and Shiraz in Yazd. The masjid represents for Yazd, a larger phenomenon of the Timurid patronage *of madrasa-khanqah* complexes as a unifying and propagandistic strategy to control a large and diverse empire (Blair and Bloom, 1994).

Parallels can also be seen in the Timurid nobleman-noblewoman character of this patronage as reflected in Timur and his wife, Saray Mulk Khanum's commission of the Bibi Khanum mosque in Samarkand or Shah Rukh as well as his wife Gawharshad's patronage of complexes in Mashhad and Herat (Hillenbrand, 1999b).

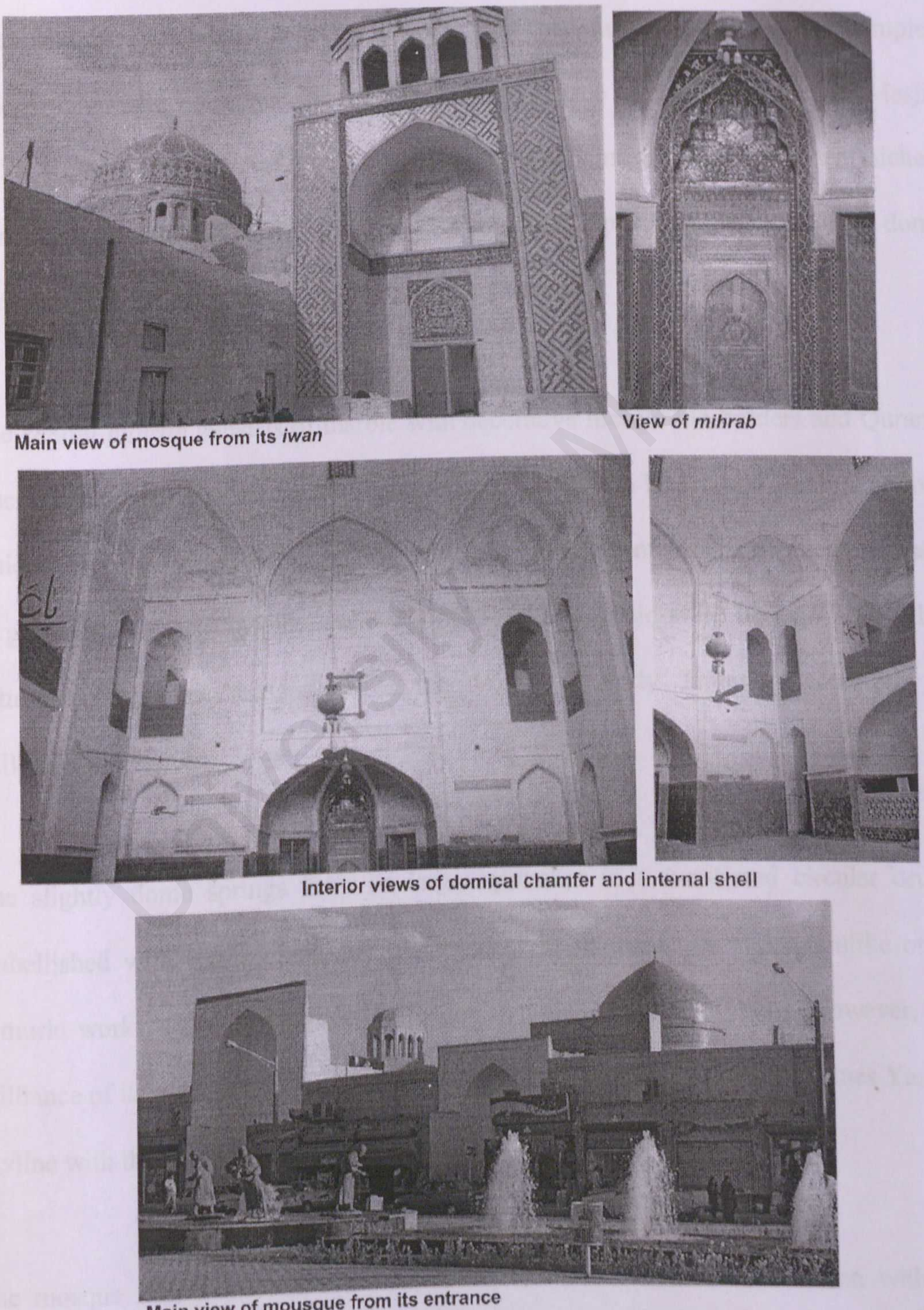


Figure 4. 35: Illustration of exterior, interior views of the dome and its chamber (Sources: The Iranian Ministry of the Cultural Heritage; www.archnet.org).

ii. Architecture: The mosque is built of mud brick finished with white washed plaster, along the traditional Iranian four-*iwan* structure around a square courtyard with no minarets. The stepped screens of the *qibla* (direction towards Mecca, and hence Muslim prayers) and the vaulted bays of the internal facades of the court appear to be dominate over the court's modest proportions. The great central dome, the primary *iwan*, and the *qibla* screen, together form the major architectural feature of the complex (Memarian, 1988; fig. 4.36). Aesthetic traditions from the Masjid-i Jami and the Masjid of Pir Husayn Damghani of Yazd are continued in this masjid, with the use of niches, windows and galleries to relieve the visually dominant supporting members of the dome and *iwan* (fig. 3.37).

The central *mihrab* consists of marble with decorative mosaic tile borders and Quranic inscriptions. The celebrated portal is ornamented with both Naskh and Thuluth scripts, which reveals details of the institution's Waqf or endowment. Panels of faience mosaic or glazed tile mosaic in blue, yellow, white and black colors are interspersed within patterned brickwork facades, as is the typical of early Timurid decorative art (Hillenbrand, 1999b).

The slightly dome springs from its large *squinches* in a two-tiered circular drum, embellished with bands of mosaic tile inscriptions in the Kufic script. Unlike other Timurid works, the mosque does not feature complex decorative vaults. However, the brilliance of its outer dome's lotus petal gores in turquoise blue tile work defines Yazd's skyline with the similar dome of the Masjid-i-Jami (Hillenbrand, 1999b).

The mosque influenced subsequent Islamic architecture of the central Iran with its introduction of a shorter *iwan* covered with a cloister vault. The mosque also features a novel innovation in incorporating a wind tower within the *mihrab*, a feature later seen in the Masjid-i Sar-i Rik of Yazd. The mosque today is identified with a later nineteenth century additions to its complex, that is, the Takieh-ye Mir Chaqmaq. The site has in recent times been the focus of intense conservation efforts and public concerns to revive this valuable historic complex and the adjacent Haji Qanbar bazaar (Pope, 1971; Golombek and Wilber, 1988).

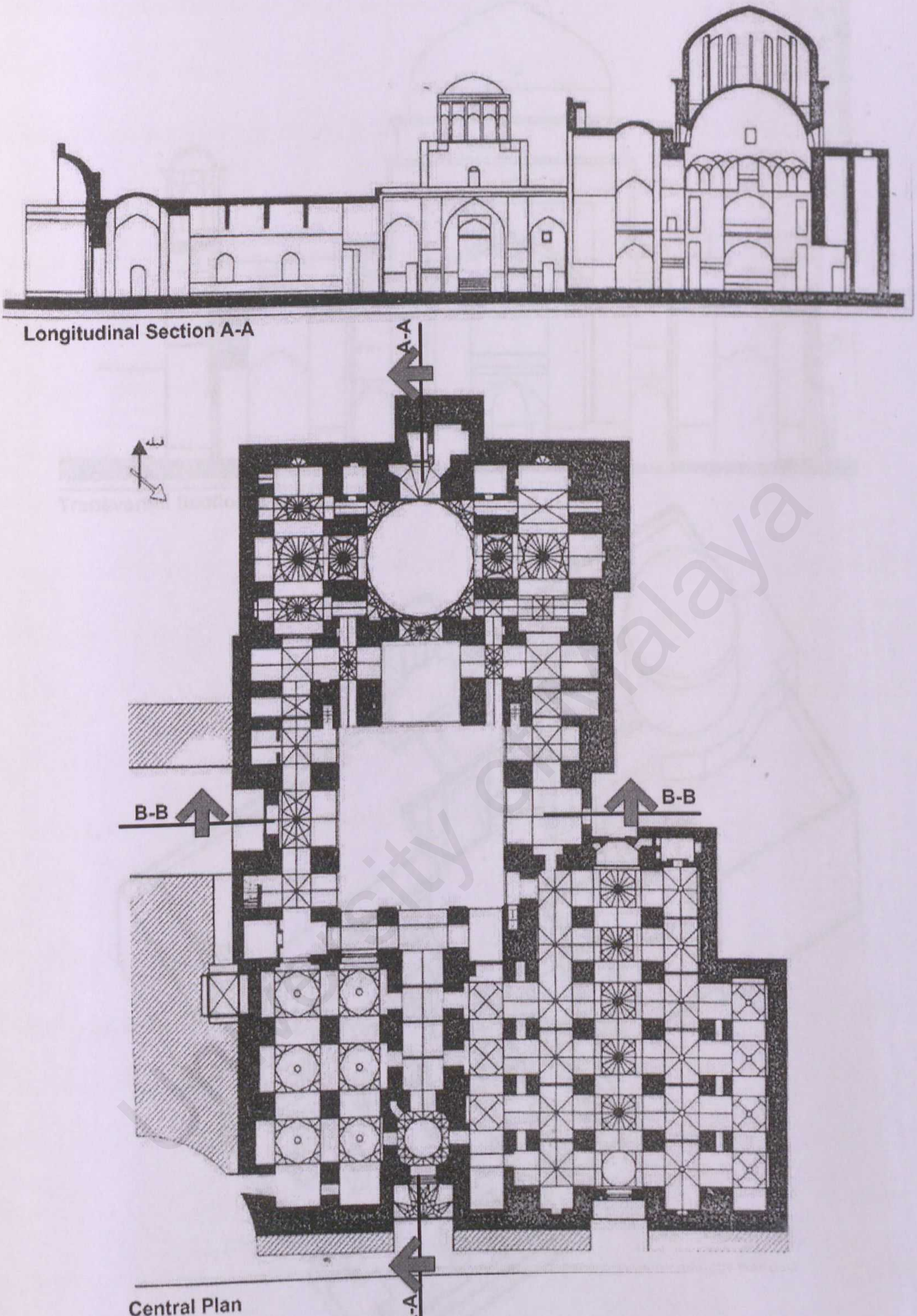
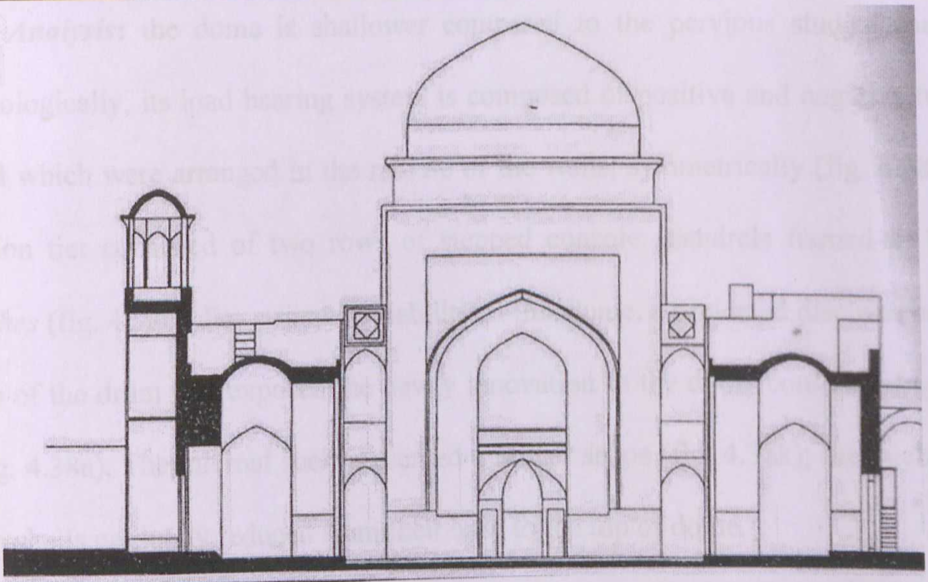
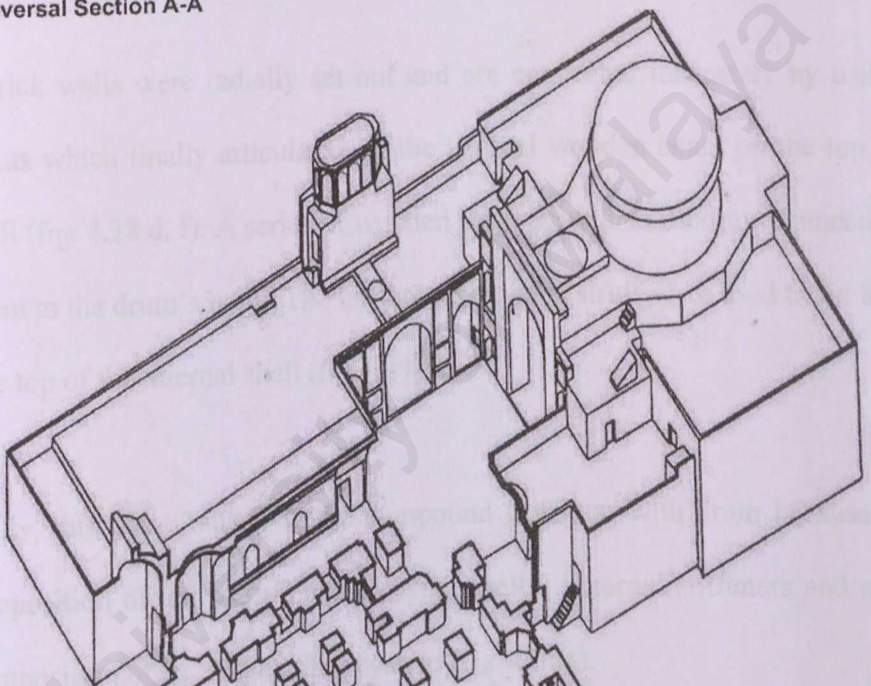


Figure 4. 36: Various architectural drawings of case 8 (Source: The Iranian Ministry of the Cultural Heritage).



Transversal Section A-A



Isometric perspective of mosque

4. 37: Illustrations of various architectural drawings of case 8 (Continued) (Source: The Iranian Ministry of the Cultural Heritage).

iii. Analysis: the dome is shallower compared to the pervious studied samples. Morphologically, its load bearing system is composed of positive and negative tunnel-vaulted which were arranged in the middle of the walls, symmetrically (fig. 4.38c). Its transition tier consisted of two rows of stepped console spandrels framed in bigger *squinches* (fig. 4.38b). For structural stability of this dome, a projected disc was built on the top of the drum that exposed the newly innovation in the dome construction in this era (fig. 4.38a). The internal shell presented a saucer shape (fig. 4.38k); the thicknesses of both shells gradually reduced from their base to the top of dome.

Some 16 brick walls were radially set out and are connected intricately by using the wooden struts which finally articulated on the vertical wooden beam on the top of the internal shell (fig. 4.38 d, f). A series of wooden struts were also used for connecting the whole system to the drum's body. The horizontal wooden struts were used to fix 8 radial walls on the top of the internal shell (fig.4.39).

Typologically, this dome ranked in the compound grammar with drum because of the special composition of its internal and external shells, internal stiffeners and also the specific composition of its load bearing system (fig. 4.38a).

Following geometrical analysis of this sample, a four-centered profile with the geometrical characteristics derived for its external shell which may set according to the proposed parametric system (fig. 4.38, f):

- External shell: $\left\{\begin{bmatrix} 4/8ab \\ 0 \end{bmatrix}, \angle 25, \begin{bmatrix} 2/8ab \\ 5/16ab \end{bmatrix}\right\}$

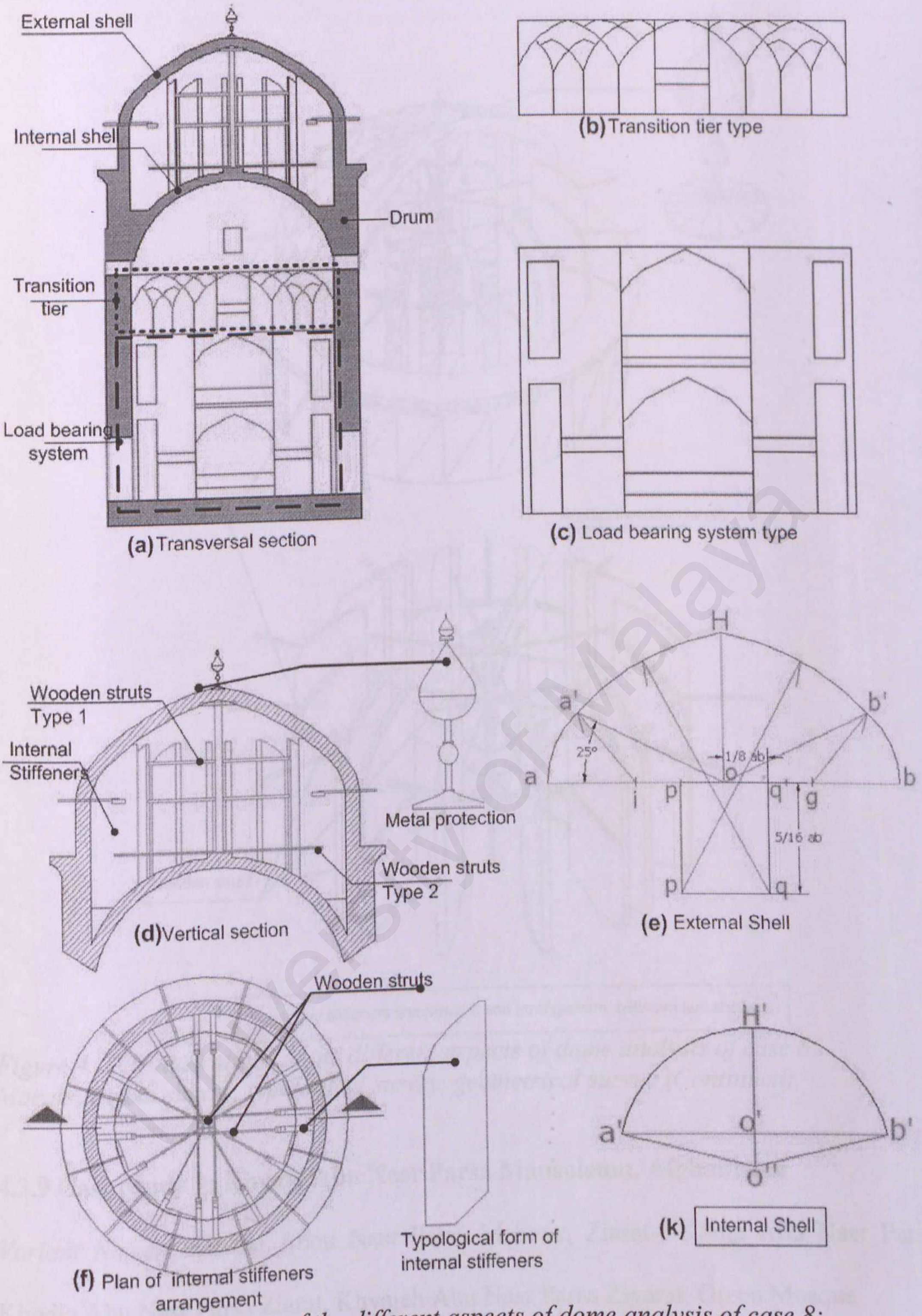


Figure 4. 38: Illustrations of the different aspects of dome analysis of case 8: Morphological survey, typological survey, geometrical survey.

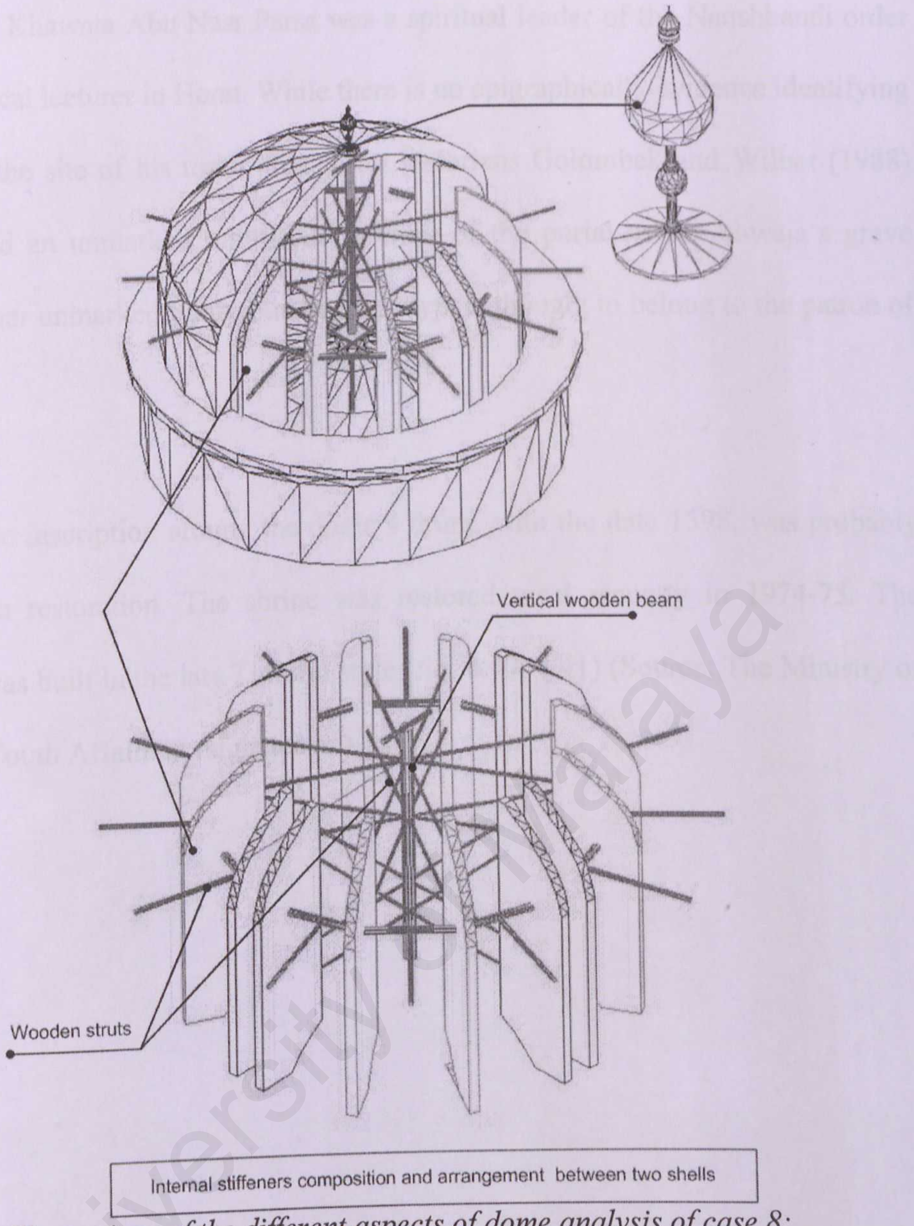


Figure 4. 39: Illustrations of the different aspects of dome analysis of case 8: Morphological survey, typological survey, geometrical survey (Continued).

4.3.9 Case Study 9: Khvaja Abu Nasr Parsa Mausoleum, Afghanistan

Variant Names: Khvaja Abou Nasr Parsa Mosque, Ziarat-i Khoja Abu Nasr Parsa, Khodja Abu Nasr Parsa Ziarat, Khvajeh Abu Nasr Parsa Ziyarat, Green Mosque

Location: Balkh, Afghanistan

Date: Between 1460 and 1598 A.D.

Style/Period: Timurid/ 15th and 16th Centuries

Building Types: Funerary

Building Usage: Tomb, Shrine

i. History: Khawaja Abu Nasr Parsa was a spiritual leader of the Naqshbandi order and a theological lecturer in Herat. While there is no epigraphically evidence identifying his shrine as the site of his tomb, though art historians Golombek and Wilber (1988) have identified an unmarked tombstone in front of the portal as the khwaja's grave marker. Another unmarked tomb found in the crypt is thought to belong to the patron of this shrine.

The tiled kufic inscription around the dome's drum, with the date 1598, was probably placed after a restoration. The shrine was restored most recently in 1974-75. The mausoleum was built in the late Timurid style (fig. 4.40; 4.41) (Source: The Ministry of Culture and Youth Affairs in Afghansitan).

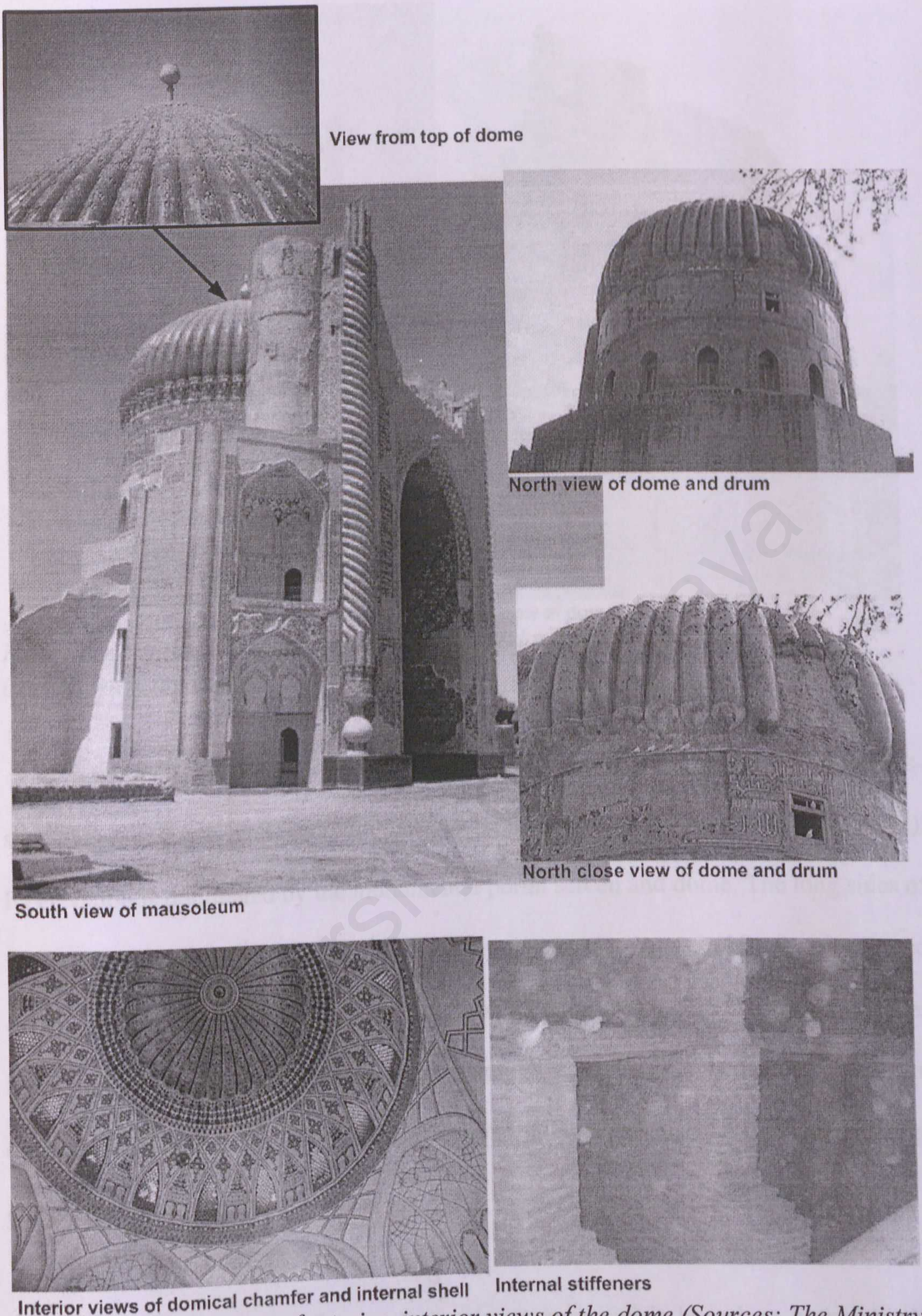
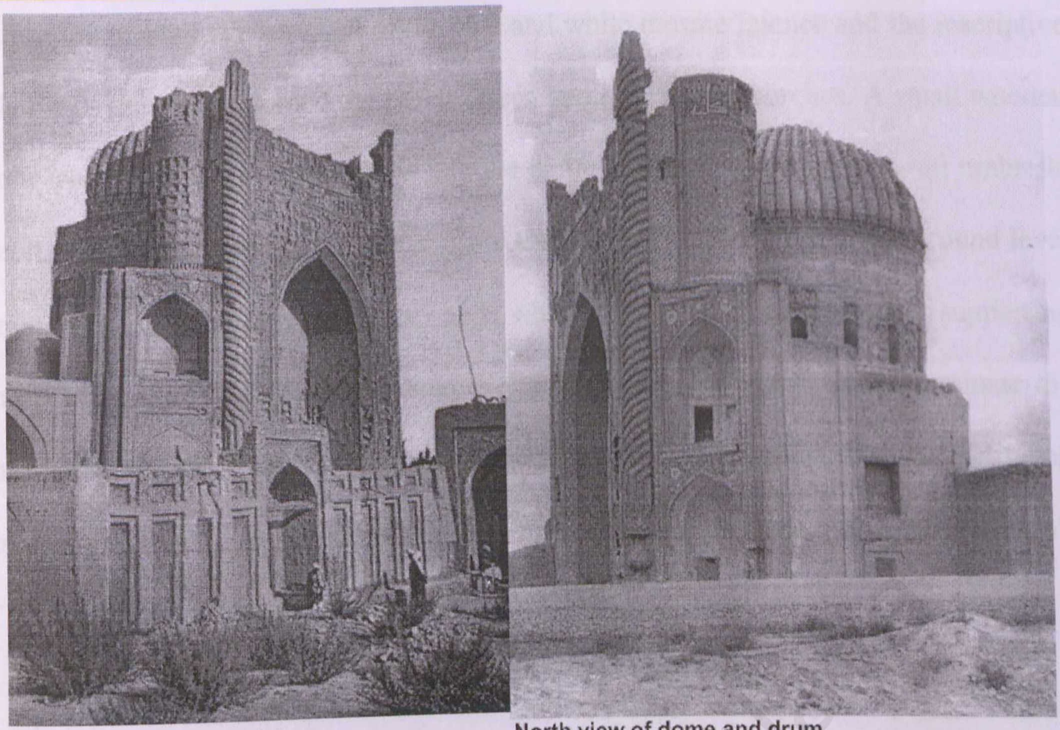


Figure 4. 40: Illustration of exterior, interior views of the dome (Sources: The Ministry of Culture and Youth Affairs in Afghanistan; <u>www. archnet.org</u>).



South view of dome and drum

North view of dome and drum

Figure 4. 41: Illustration of exterior views of the dome before major conservation (Source: www. archnet.org).

***ii. Architecture*:** The plan of the shrine is a chambered square enveloping a cross-shaped dome chamber aligned with *qibla* along the southwest-northeast axis (fig. 4.42). Its elevation is dominated by the monumental portal screen and dome. The long sides of the exterior were carved with eight-meter-deep rectangular *iwans*, while the chambered corners had bi-level, five-sided porches; the roofs of the *iwans* and the upper porches have largely collapsed, exposing the octagonal substructure of the circular drum (Source: Website of Society for the Preservation of Afghanistan's Cultural Heritage (SPACH).

The towering portal screen frames the northeast *iwan* and is bound on both sides by engaged cabled columns with bulbous bases. Its top section, now collapsed, had an arched gallery that rose taller than the dome. The bi-level porches flanking the portal are topped with minarets, of which the shafts remain. Stairs entered from the corner porches give access to the upper porches, the minarets and the roof.

Only fragments have survived of the blue and white mosaic faience and the inscriptive tile bands that once adorned the portal screen and its flanking porches. A small wooden door leads from the northeast *iwan* into the dome chamber, crowned by a tall umbrella vault. The four arched niches that animate the walls of the chamber at the ground level are doubled in number at the gallery level with the addition of corner arches supporting the dome's *squinches*. Sixteen windows placed at the rim of the vault illuminate the interior. The dome chamber has a small *mihrab* niche on the southwest wall, facilitating its use as a prayer hall (Source: Website of Society for the Preservation of Afghanistan's Cultural Heritage (SPACH).

The crypt directly below the dome chamber has a low vault supported by intersecting arches and *squinches*. A column was added later to support the crown of the crypt vault. The platform with tombstones before the main portal was also added at a later date. The dome, its *muqarnas* base and its drum are also covered with plain, floral and inscriptive tiles dominated by shades of blue (Byron, 1939).

The dome is basically called, 'fluted' and resting on stalactite corbels; above the ground, sits above a colorfully tiled octagonal base (*see* fig. 4.40). The portal is flanked by magnificent corkscrew pillars. A small section of tiles on the dome displayed damage resulting from a rocket hit during the civil war at 1974; however, restoration suffered from the lack of maintenance; an authorized construction of a new mosque attached to such façade destroyed its original design.

A crack in the South Eastern part of the dome may have been caused by an earthquake during factional fighting in 2003. The department of historical monuments of Balkh has undertaken repair work on the rocket hit in the southern façade and the retiling of a section of the dome (*see* fig. 4.40) (Source: The Ministry of Culture and Youth Affairs in Afghanistan).

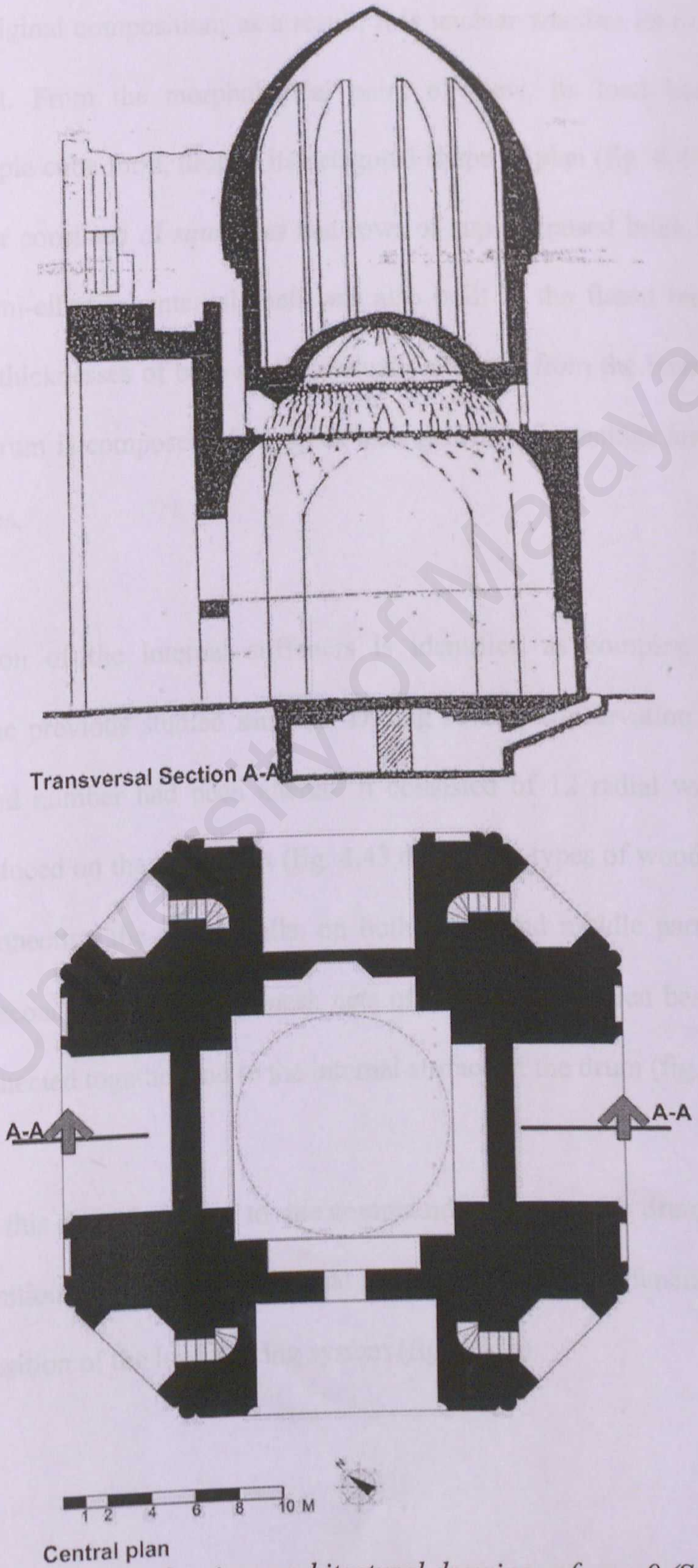


Figure 4. 42: Illustrations of various architectural drawings of case 9 (Source: The Ministry of Culture & Youth Affairs in Afghanistan).

iii. Analysis: it may consider as ample remaining sample of uniform style of the Timurid architecture in Afghanistan. As, it is mentioned before, this dome was collapsed and then conserved ages before when there existed not clear documentation regarding its original composition; as a result, it is unclear whether its originality was changed or not. From the morphological point of view, its load bearing system presented a simple cube form, despite its octagonal shape of plan (fig. 4.43c). The zone of transition tier consisted of *squinches* and rows of superimposed brick brackets (fig. 4.43b). The semi-elliptical internal shell was also built in the fluted techniques (fig. 4.43k) and the thicknesses of both shells gradually reduced from the base to the top of the dome. Its drum is composed of complex arrangement of openings and windows in regular distances.

The composition of the internal stiffeners is identified as complex and intricate compared to the previous studied samples. During several conservation interventions, their setting and number had been altered. It consisted of 12 radial walls with their thicknesses reduced on the upper part (fig. 4.43 d, e). Two types of wooden struts were utilized for connecting the radial walls: on both upper and middle parts of its radial walls. In the second type, by using mesh nets of horizontal wooden beams, the radial walls were connected together and to the internal surface of the drum (fig. 4.44).

Typologically, this dome belonged to the compound grammar with drum because of its special composition of internal and external shells and internal stiffeners as well as the specific composition of the load bearing system (fig. 4.43a).

Results of geometrical analysis suggest a four-centered profile with the following geometrical characteristics which can be formulated according to the proposed parametric system (fig. 4.43f):

- External shell: $\left\{ \begin{bmatrix} 2/8ab \\ 0 \end{bmatrix}, 0, \begin{bmatrix} 0 \\ 0 \end{bmatrix} \right\}$

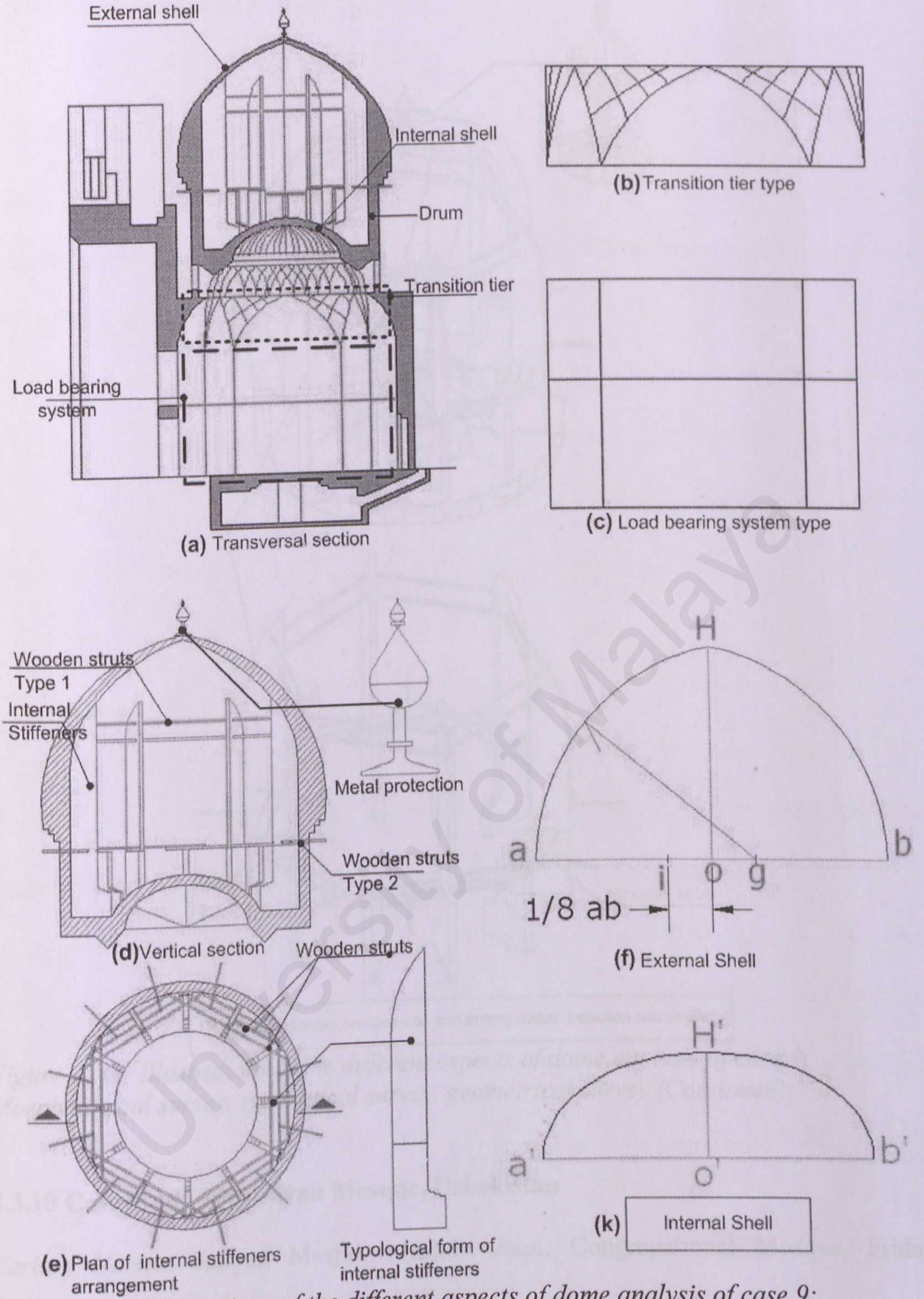


Figure 4. 43: Illustrations of the different aspects of dome analysis of case 9: Morphological survey, typological survey, geometrical survey.

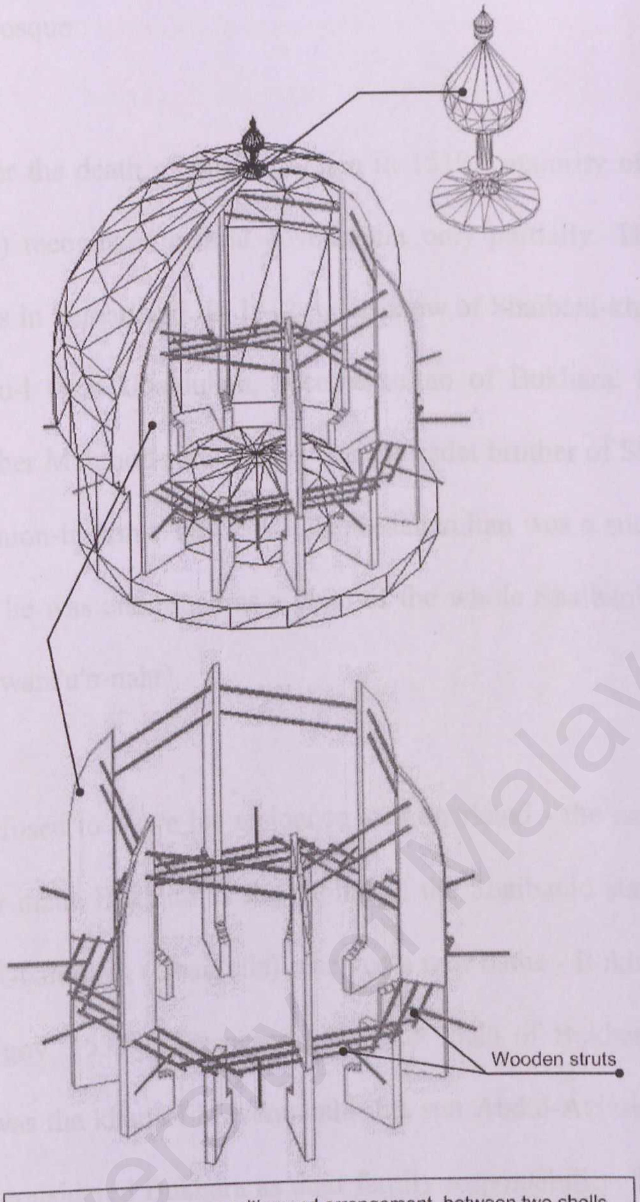


Figure 4. 44: Illustrations of the different aspects of dome analysis of case 9: Morphological survey, typological survey, geometrical survey (Continued).

4.3.10 Case Study 10: Kalyan Mosque, Uzbekistan

Variant Names: Kalyan Masjid, Masjid-i Jami, Congregational Mosque, Friday Mosque, Poi Kalyan Mosque, Poi Kalan Mosque

Location: Bukhara, Uzbekistan

Date: early 1400, 1514 A.D.

Style/Period: Shaybanid, Timurid /15th and 16th Centuries

Building Type: Religious

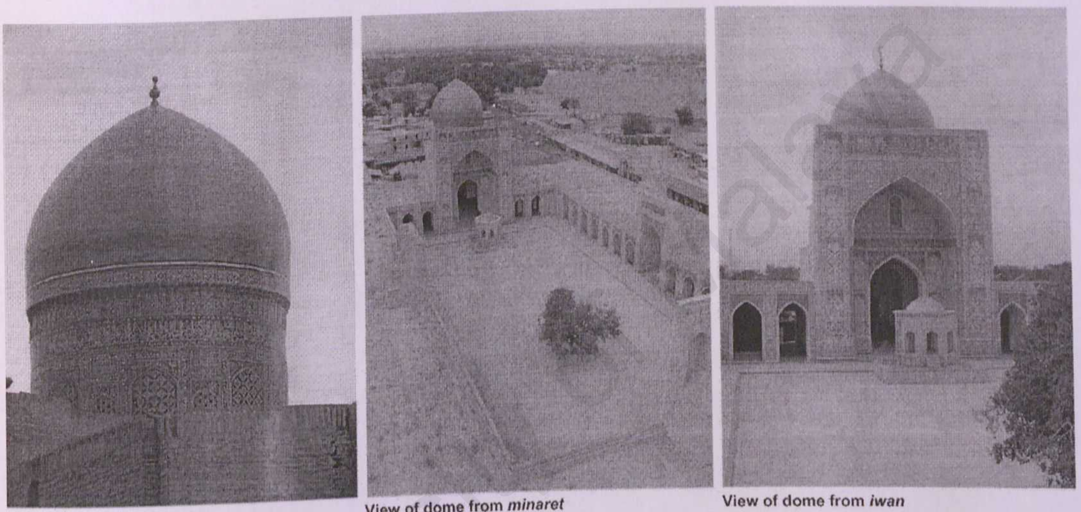
Building Usage: Mosque

***i. History*:** After the death of Shaibani-khan in 1510, majority of the local rulers (emirs and sultans) recognized central government only partially. The capital of the Shaibanid state was in Samarkand. In 1512 the nephew of Shaibani-khan, young prince Muizz ad-Din Abu-l Gazi Ubaidullah, became sultan of Bukhara. He inherited the power from his father Mahmud-sultan, who was the cadet brother of Shaibani-khan and his faithful companion-in-arms. Till 1533 Ubaidullah-sultan was a successful governor of Bukhara, when he was enthroned as a khan of the whole Shaibanid state - khan of Maverannahr (Ma wara'u'n-nahr).

Despite this, he refused to move his residence to Samarkand - the capital of the State. Moreover, he later made Bukhara as the capital of the Shaibanid state. After that, the state governed by Ubaidullah (Ubaidulla) received a new name - Bukhara khanate. Thus Ubaidullah-khan (gov. 1533-1539) became the first khan of Bukhara khanate. While Ubaidullah-khan was the khan of Maverannahr, his son Abdul-Aziz-khan was the khan of Bukhara. They considered Bukhara as their family responsibility. They were patriots of Bukhara, and therefore they constantly were anxious for the success of the city (Blunt, 1973).

The fact that the governor of Bukhara (1514 A.D.) construct such a grand mosque, which could rival the symbol of royal Samakand - the Bibi-khonim Mosque, shows a tendency to eventually make Bukhara the capital of the Shaibanid state. By the construction of Kalyan Mosque Ubaidullah-sultan started formation of the new capital, rather than to fight for domination over Samarkand, which by the way forever had hostile feelings toward the Shaibanids (fig. 4.45).

On the other view, the Kalyan mosque is one of the outstanding monuments of Bukhara, dating back to the fifteenth century. According to data from archaeological excavations, the original Karakhanid Djuma Mosque was destroyed by fire and dismantled, apparently at the time of the Mongolian invasion. Soon later, it was rebuilt, but this reconstructed mosque did not remain long. A new mosque was erected in the fifteenth century, at the time of the Shaibanids, according to written sources of the time (Michell, 1978; fig. 4.45).



View of dome from roof View of dome from *minaret* View of dome from *iwan*

Figure 4. 45: Illustration of exterior views of the dome and mosque (Source: www.panoramio.com/photo/2656872).

***ii. Architecture*:** Kalyan Mosque (Maedjid-i kalyan), arguably completed in 1514, is equal with the magnitude of Bibi Khanum mosque in Samarkand. Although they are of the same type of building, but their decorations and ornaments are absolutely different. The roofing (of 288 domes) of the galleries encircling the courtyard of Kalyan Mosque rests on 208 pillars (fig. 4.46).

On the other hand, 288 monumental pylons serve as a support for the multi domed roofing of the galleries encircling the courtyard of Kalyan Mosque. The longitudinal axis of the courtyard ends up with a portal to the main chamber (*maksura*) with a cruciform hall, topped with a massive blue cupola on a mosaic drum (fig. 4.47). The edifice keeps many architectural curiosities, for example, a hole in one of domes. Through this hole one can see the foundation of Kalyan Minaret. Then moving back step by step, one can count all belts of brickwork of the minaret to the rotunda (Golombek and Wilber, 1988). *Squinches* support a vaulted inner of dome and are capped by a spherical blue pointed dome upon a drum. This structure still dominates the skyline of Bukhara (Golombek and Wilber, 1988).

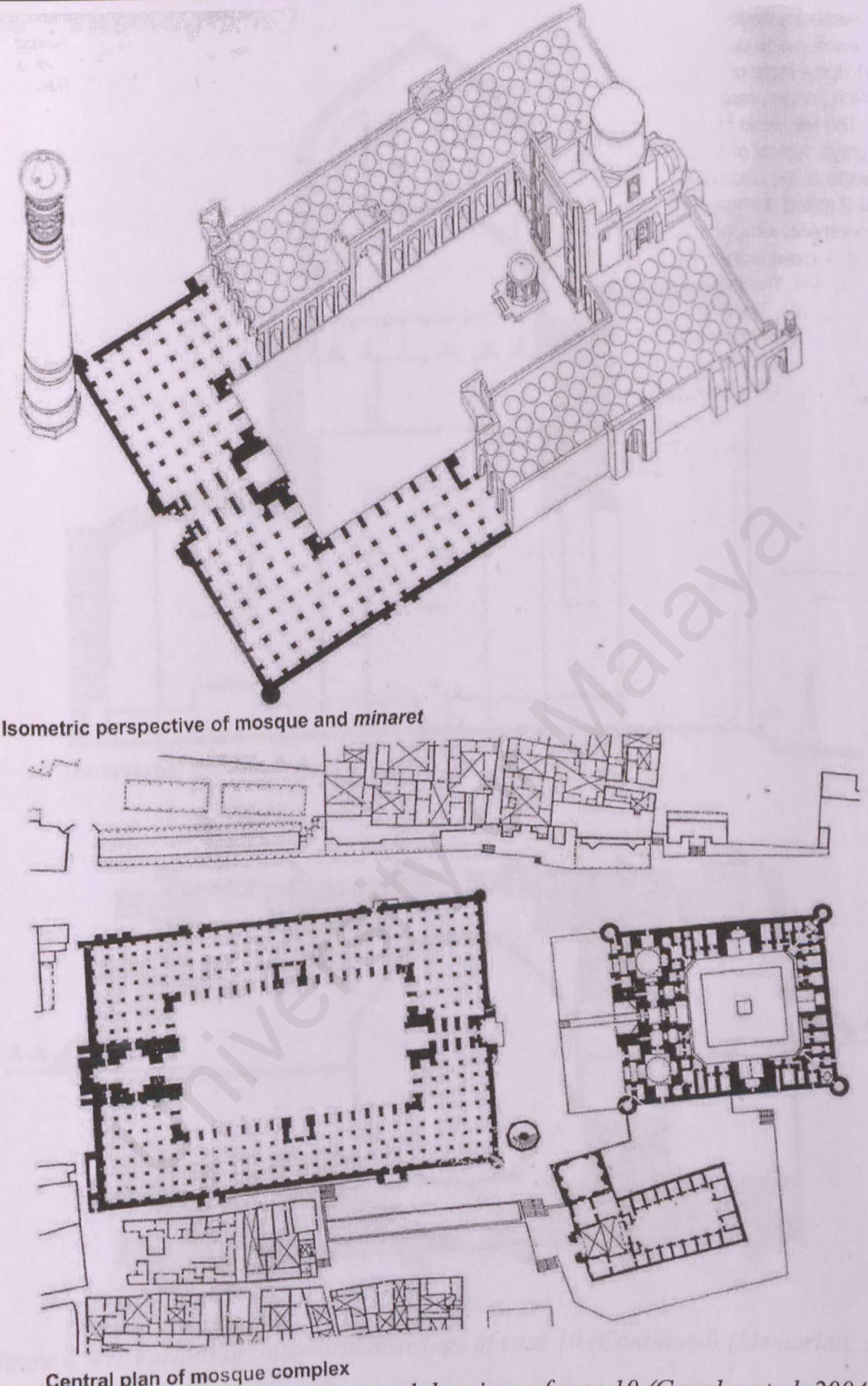


Figure 4. 46: Various architectural drawings of case 10 (Gangler et al. 2004).

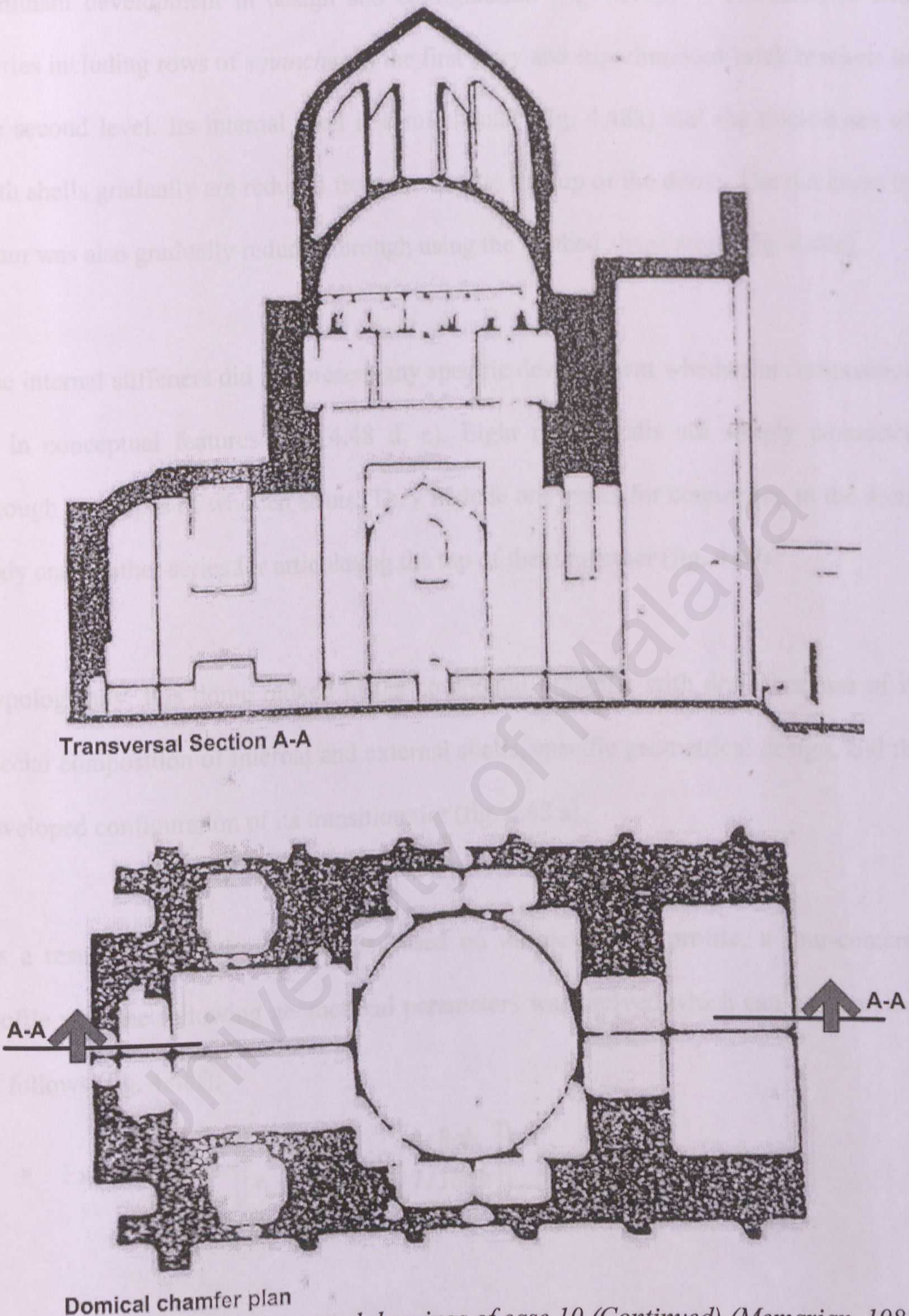


Figure 4. 47: Various architectural drawings of case 10 (Continued) (Memarian, 1988).

iii. Analysis: this dome conceptualism is the typical style of 16th century Shaybanid architecture. Morphologically, its load bearing system did not present any specific development in design and configuration. It consisted of the typical use of the positive and negative vaulted systems (fig. 4. 48c). But its transition tier showed a dominant development in design and configuration (fig. 4.48b). It consisted of two stories including rows of *squinches* in the first story and superimposed brick brackets in the second level. Its internal shell is semi-circular (fig. 4.48k) and the thicknesses of both shells gradually are reduced from the base to the top of the dome. The thickness of drum was also gradually reduced through using the toothed shape steps (fig. 4.48a).

The internal stiffeners did not present any specific development whether in composition or in conceptual features (fig. 4.48 d, e). Eight radial walls are simply connected through two types of wooden struts. They include one series for connecting to the drum body and another series for articulating the top of them together (fig. 4.49).

Typologically, this dome ranked in the compound grammar with drum because of its special composition of internal and external shells, specific geometrical design, and the developed configuration of its transition tier (fig. 4.48 a).

As a result of geometrical analysis based on the developed profile, a four-centered profile with the following geometrical parameters was derived which can be expressed as follows (fig. 4.48f):

- External shell: $\left\{\begin{bmatrix} 2/8ab \\ 0 \end{bmatrix}, \angle 30, \begin{bmatrix} 6/8ab \\ 7/16ab \end{bmatrix}\right\}$

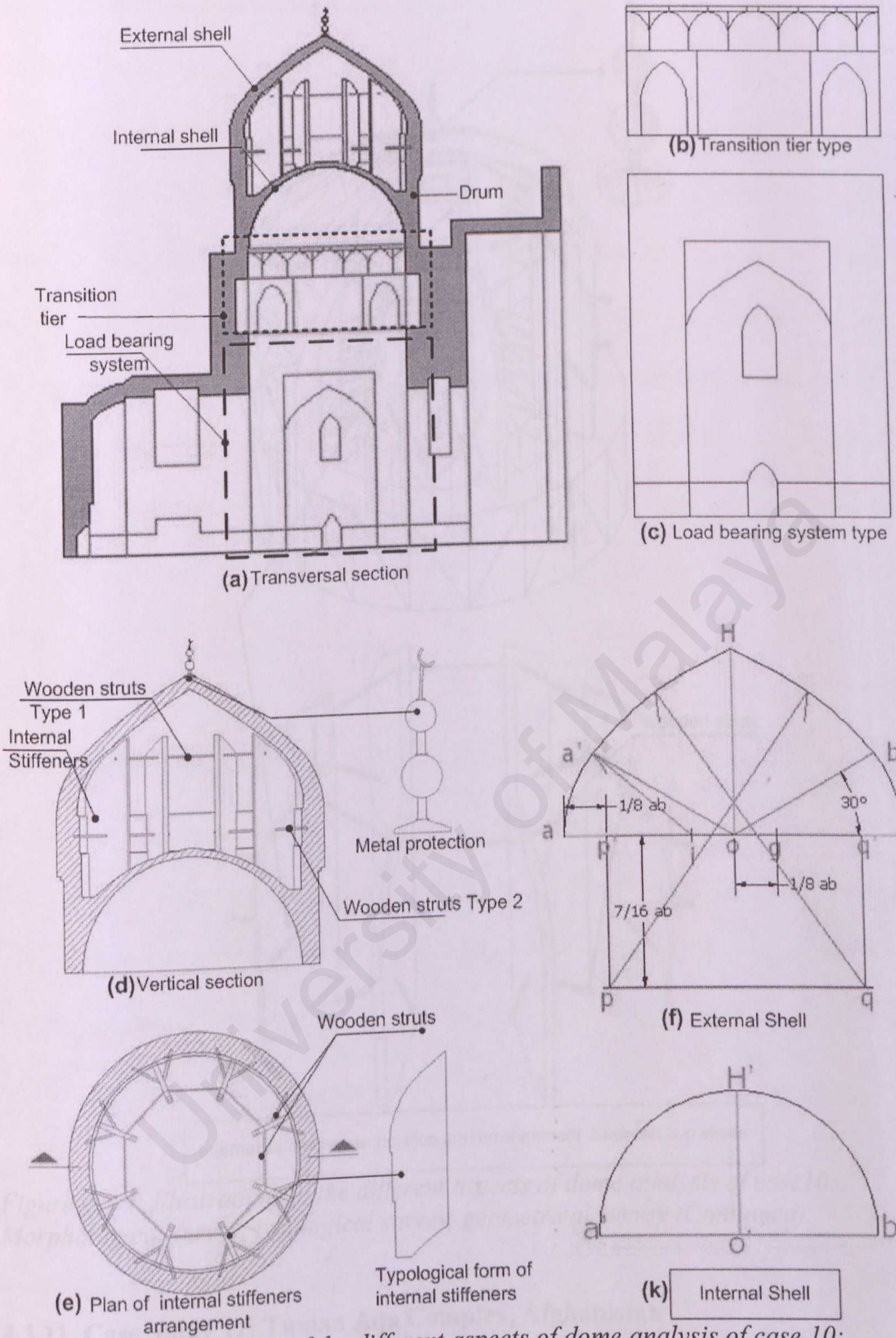


Figure 4. 48: Illustrations of the different aspects of dome analysis of case 10: Morphological survey, typological survey, geometrical survey.

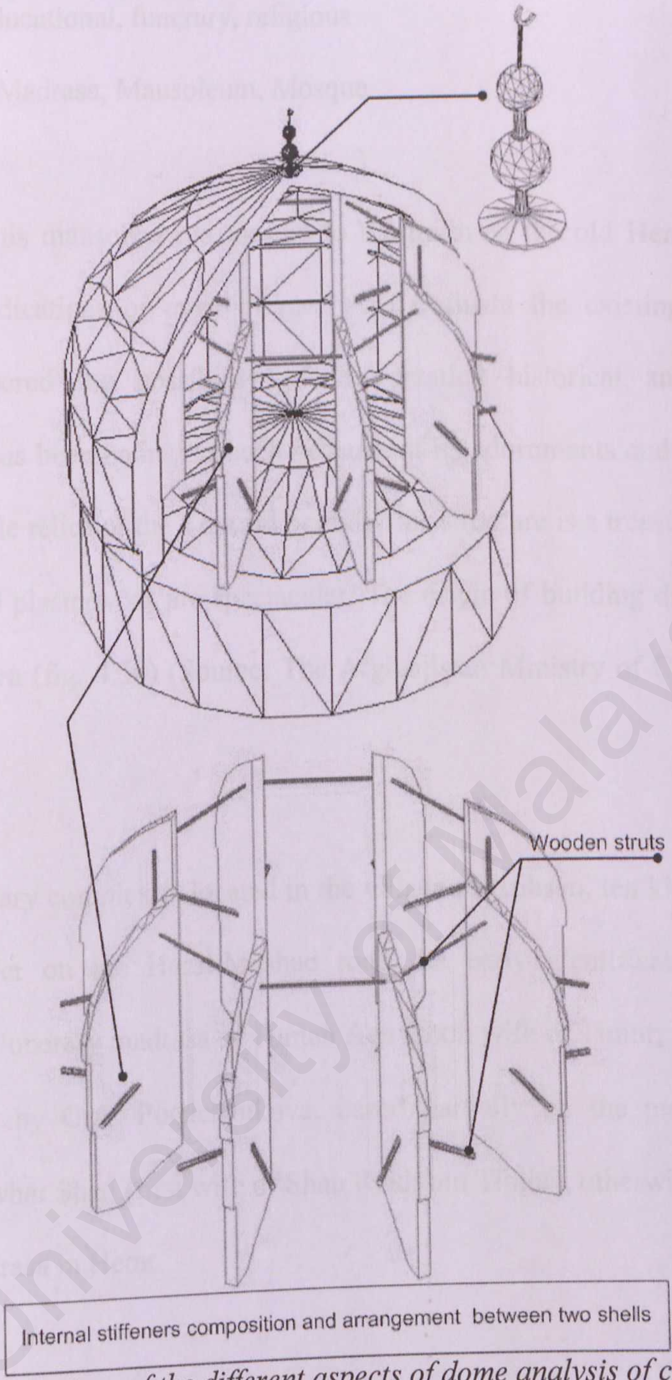


Figure 4. 49: Illustrations of the different aspects of dome analysis of case10: Morphological survey, typological survey, geometrical survey (Continued).

4.3.11. Case Study 11: Tuman Aqa Complex, Afghanistan

Variant Names: Tuman Agha Mausoleum and Madrasa, Funerary Complex of Tuman Agha

Location: Kuhsan, Afghanistan

Date: 1440-41 A.D.

Style/Period: Timurid/ 15th century

Building Type: educational, funerary, religious

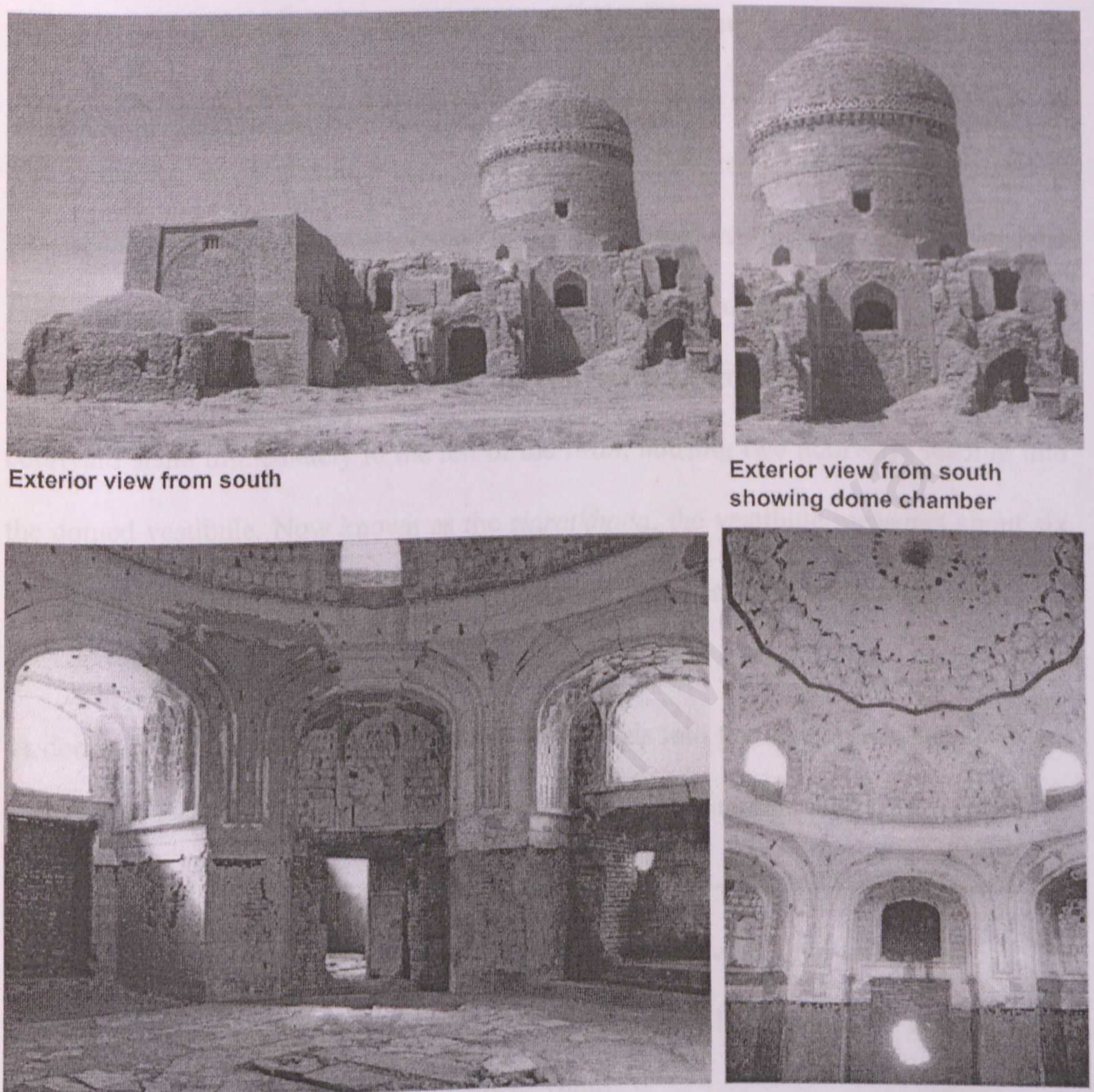
Building Usage: Madrasa, Mausoleum, Mosque

i. History: This mausoleum is located to the north of the old Herat. The lack of adequate text indications or even of means to evaluate the existing evidence has constantly hampered the possibility of the detailed historical and architectural explanations. It has been named as such because of its adornments and epigraphs. It is one of the valuable relics of the Timurid period. This structure is a treasure in the aspect of art; its tile and plasterwork are spectacular. The origin of building dates back to the before Timurid era (fig. 4.50) (Source: The Afghanistan Ministry of Culture & Youth Affairs).

This ruined funerary complex is located in the village of Kuhsan, ten kilometers east of the Iranian border on the Herat-Mashad road. Its early identification by Nicolai Khanykov as the funerary madrasa of Tuman Aqa (sixth wife of Timur, 1366-144?) was rejected in 1968 by G.A. Pugachenkova, based partially on the monument's local attribution to Gawhar Shad (first wife of Shah Rukh bin Timur), otherwise thought to be buried in her madrasa in Herat.

Recent work by Bernard O'Kane confirms that the complex was commissioned by Tuman Aqa during her retirement years in Kuhsan. The domed burial chamber and prayer hall remaining today are thought to be part of a two or four-iwan madrasa, whose date of completion 1440-41 (840 A.H.) is inscribed in small Kufic script on the cuerda seca tiles of the dome's drum. It is not certain whether the queen was buried here or in her eponymous khanqah at the Shah-i Zinda Complex (Samarkand) after her death.

Remains of a caravanserai or ribat, also built by Tuman Aqa, are located northwest of Kuhsan.



Exterior view from south

Exterior view from south showing dome chamber

Interior view of dome chamber looking southwest

Interior view of dome chamber, looking south

Figure 4. 50. Illustration of exterior and interior views of the dome and mausoleum (Sources: The Afghanistan Ministry of Culture & Youth Affairs).

ii. Architecture: This mausoleum comprises a courtyard, brick dome, three porticos and a few porches and two archaic altars with inscriptions in Kufic script. It has a beautiful and valuable altar adorned with plasterwork and vaulted inscriptions. Two altars dating to the Timurid era are adorned with inscriptions in 'Thuluth' script. There are also other inscriptions with sacred verses, in 'Kufic' and 'Thuluth' script.

There is an elevated porch between two nocturnal areas in the western front that have chambers in its either sides. One of the 'Kufic' inscriptions is white and the other is maroon in color (Source: The Afghanistan Ministry of Culture & Youth Affairs).

The complex, as it stands today, consists of an octagonal dome chamber and a rectangular hall to its southwest, joined by a small domed vestibule in between. A deep *iwan* with a collapsed vault and portal screen precedes the dome chamber; this was the southern *iwan* of the *madrasa* courtyard. Fragments of the chamfered corner of the courtyard stand immediately to the left of the *iwan*, housing two doorways leading into the domed vestibule. Now known as the *ziaratkhana*, the vestibule measures about six meters per side and has survived in poor condition with a partially collapsed dome.

A doorway on the west wall of the *ziaratkhana* leads into the rectangular hall. The hall measures is about six and a half meters wide and thirteen meters long (north-south) on the interior and is also entered from the North and South. Its vaulted roof and central dome are supported on five transverse archways, two of which are embedded into the north and south walls. A *mihrab* carved into its western hall shows that it was used as a prayer hall (masjid) (Golombek and Wilber, 1988).

The octagonal dome chamber measures about 14 meters wide on the exterior and 8 meters on the interior. It is covered with a pointed double- shell dome resting on eight heavy piers located at the corners of the octagon; these piers are connected with vaults and relatively thin walls, creating deep arched niches on the inside and shallower niches on the outside. Surfaces of the dome and the drum were originally covered with tile mosaic and cuerda seca tiles featuring inscriptions and floral and geometric motifs. Remaining segments of the large *nakshi* script on the drum and smaller *kufic* inscriptions fitted in between were read by O'Kane, and contain the date of completion.

The three southern niches have doors leading into the chamber from the *ziaratkhana*, the southern *iwan*, and a small room accessed from the *madrasa* courtyard. A fourth doorway is located inside the northern niche, while the east and west niches are pierced only with arched windows (Golombek and Wilber, 1988).

The interior of the dome chamber is adorned with *squinch*-net compositions on the niche vaults and the dome, which are filled in with *muqarnas* carvings and highlighted with painted arabesques. The *squinch*-net vaulting of the dome begins with a circular belt above the niche arches, transitioning from sixteen crossed archways to a thirty-two pointed star; the star is ringed with rows of plaster *muqarnas* raising the center of the dome for depth effect. Only a single inscription, verses from 'Imran *sura* in *thuluth* script, can be seen inside the niche leading out to the *iwan*. The neighboring *ziaratkhana* is also adorned with *squinch*-net vaulting and painted arabesques (Sources: Golombek and Wilber, 1988; The Afghanistan Ministry of Culture & Youth Affairs).

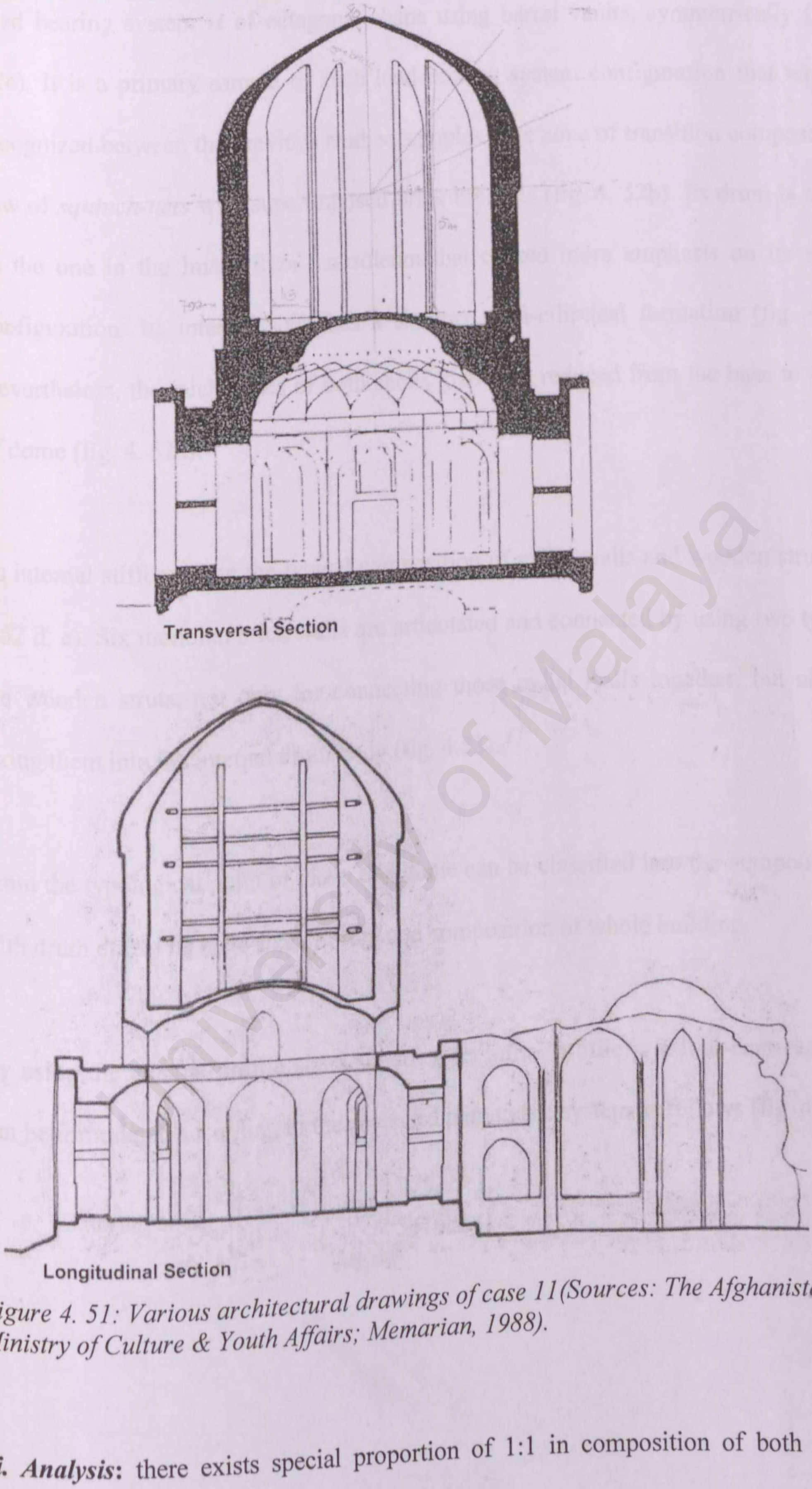


Figure 4. 51: Various architectural drawings of case 11(Sources: The Afghanistan Ministry of Culture & Youth Affairs; Memarian, 1988).

***iii. Analysis*:** there exists special proportion of 1:1 in composition of both top and bottom of the dome. In addition, after introduction of "Gadrooned domes",it rank as second type of pointed domes in the Timurid era. From the morphological aspect, its load bearing system is of octagonal shape using barrel vaults, symmetrically (fig. 4. 52c). It is a primary sample of such load bearing system configuration that were not recognized between the previous studied samples. The zone of transition composed of a row of *squinch-nets* with superimposed brick brackets (fig. 4. 52b). Its drum is as high as the one in the Imam Riza mausoleum that caused more emphasis on its vertical configuration. Its internal shell has a shallow semi-elliptical formation (fig. 4.52k). Nevertheless, the thicknesses of both shells gradually reduced from the base to the top of dome (fig. 4. 52a).

Its internal stiffeners are the typical composition of radial walls and wooden struts (fig. 4.52 d, e). Six meridian brick walls are articulated and connected by using two types of the wooden struts, not only for connecting those radial walls together, but also, for fixing them into the internal drum body (fig. 4.53).

From the typological point of view, this dome can be classified into the compound type with drum due to its huge size of drum and composition of whole building.

By using the general profile characteristics, its initial profile is a four-centered which can be formulated according to the proposed parametric system as follows (fig. 4.52f):

- External shell: $\left\{\begin{bmatrix} 4/8ab \\ 0 \end{bmatrix}, \angle 25, \begin{bmatrix} 2/8ab \\ 5/16ab \end{bmatrix}\right\}$

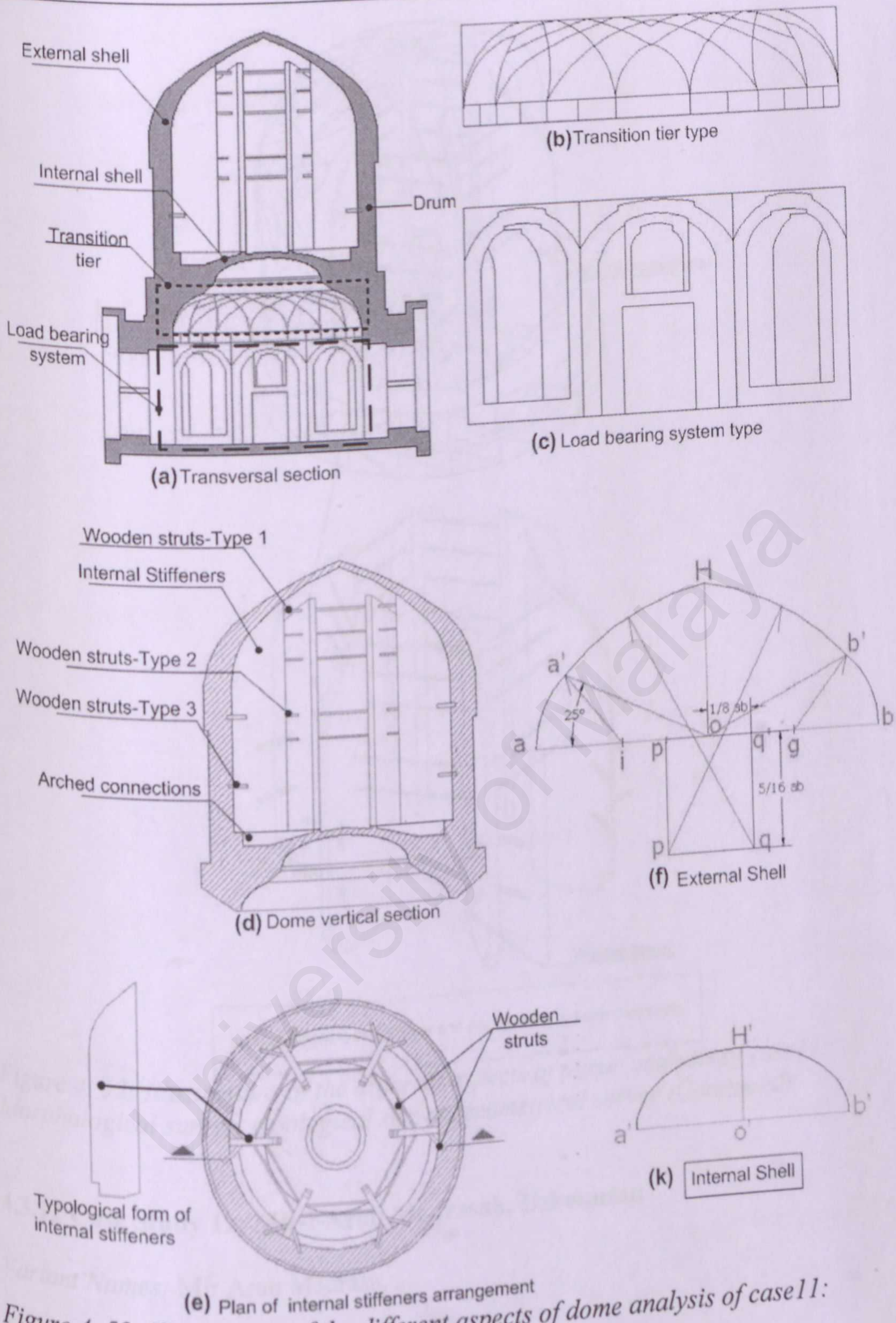


Figure 4. 52: Illustrations of the different aspects of dome analysis of case11: Morphological survey, typological survey, geometrical survey.

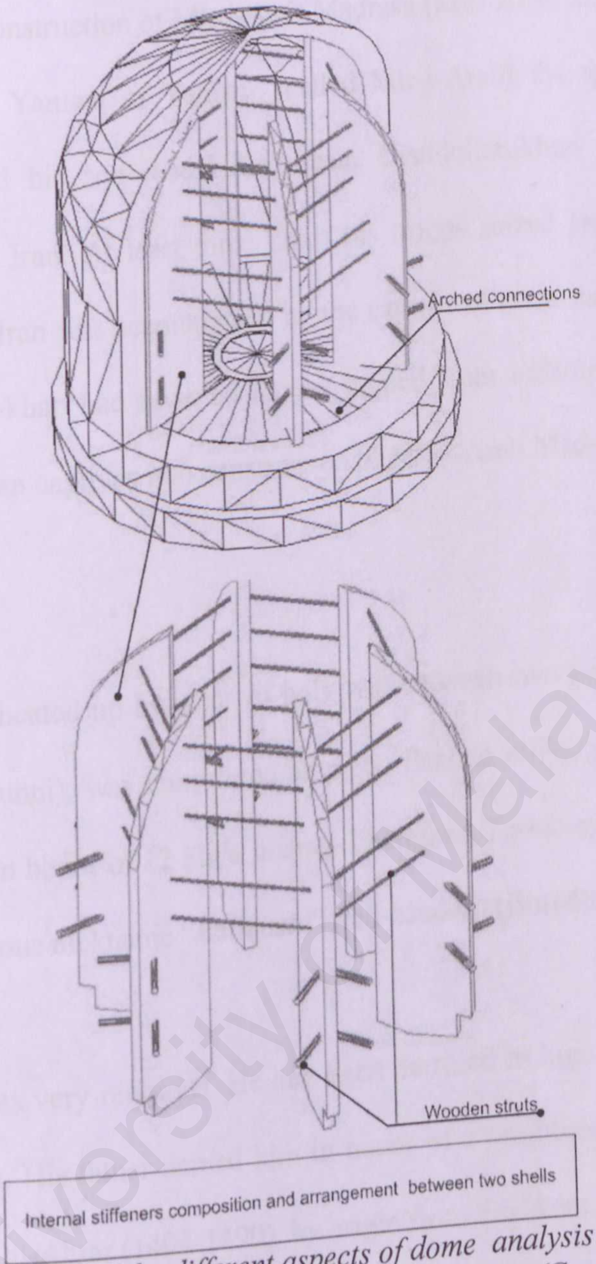


Figure 4. 53: Illustrations of the different aspects of dome analysis of case11: Morphological survey, typological survey, geometrical survey (Continued).

4.3.12 Case Study 12: Mir-i-Arab Madrasah, Uzbekistan

Variant Names: Mir Arab Madrasa,

Location: Bukhara, Uzbekistan

Date: 1535-1536 A.D.

Style/Period: Shaybanid/ 16th Century

Building Type: Educational

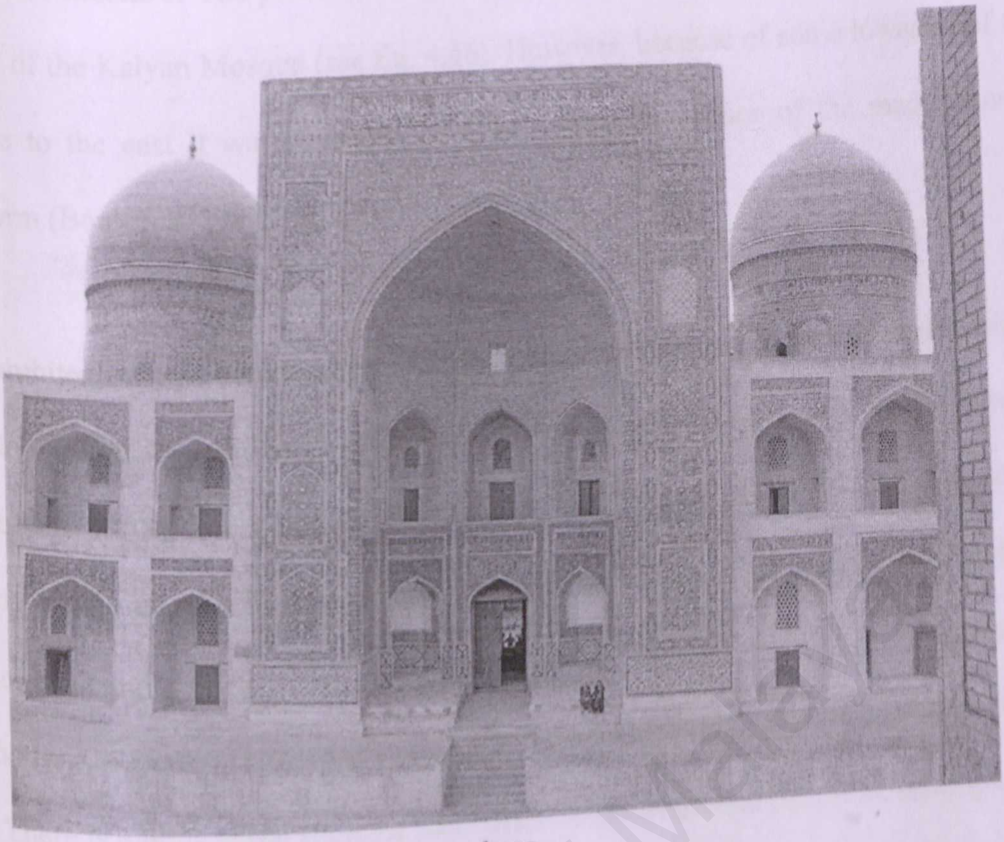
Building Usage: Madrasah

i. History: The construction of Mir-i-Arab Madrasa (Miri Arab Madrasa) is ascribed to Sheikh Abdullah Yamani of Yemen (called Mir-i-Arab) the spiritual mentor of Ubaidullah-khan and his son Abdul-Aziz-khan. Ubaidullah-khan waged permanent successful war with Iran. At least three times his troops seized Herat. Each of such plundering raids on Iran was accompanied by the capture of great many captives. They say that Ubaidullah-khan had invested money gained from redemption of more than three thousand Persian captives into construction of Mir-i-Arab Madrasa (Gangler *et la*., 2004).

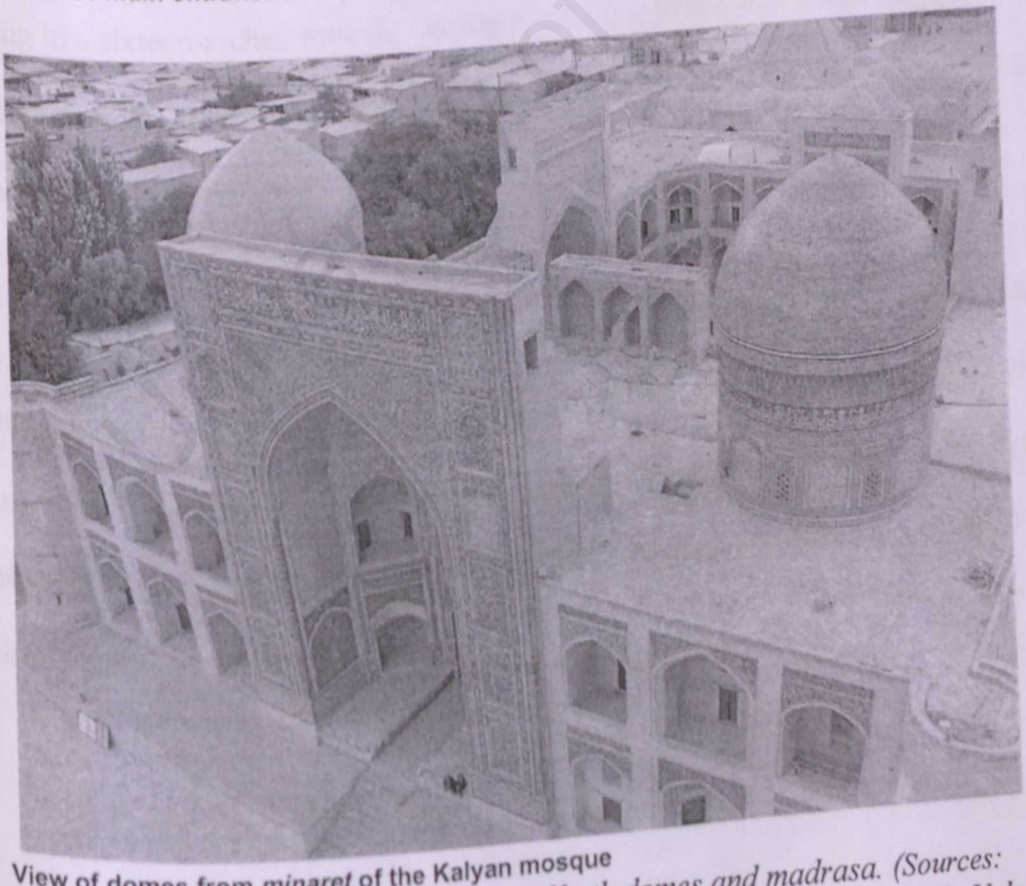
The war with Iran, heated up by ideas of holy war between two historical branches of Islam (Shi'as and Sunni), was considered as piety. Persian military man wore turbans with 12 red stripes in honor of 12 Shi'a Imams. Therefore, Turkic-speaking Sunnis gave them the contemptuous nickname "*kizilbashi*" (red-headed) (Borodina, 1987).

Ubaidullah-khan was very religious. He had been nurtured in high respect for Islam in the spirit of Sufism. His father named him in honor of a prominent sheikh of the 15th century Ubaidullah al-Ahrar (1404-1490), by origin from Tashkent province.

By the thirties of the 16th century, the time when sovereigns erected splendid mausoleums for themselves and for their relatives, was over. Khans of the Shaibanid dynasty were standard-bearers of Quranic traditions. The significance of religion was so great that even such famed khan as Ubaidullah was conveyed to earth close by his mentor in his madrasa. In the middle of the vault (*gurhana*) in Mir-i-Arab Madrasa is situated the wooden tomb of Ubaidullah-khan (fig. 4. 54). At his head is wrapped in the moulds his mentor - Mir-i-Arab. Muhammad Kasim, a senior teacher of the madrasa (died in 1047 hijra) is also interred near by here (Gangler et al., 2004).



View of main entrance of Mir- Arab *madresa*



View of domes from *minaret* of the Kalyan mosque

Figure 4. 54: Illustrations of exterior views of both domes and madrasa. (Sources: www.panoramio.com/photo/10235144; www.flickr.com/photos/acordova/729611703, Uploaded by Alan Cordova, 2007).

ii. Architecture: The portal of Miri Arab Madrasah is situated on one axis with the portal of the Kalyan Mosque (*see* fig. 4.46). However, because of some lowering of the square to the east it was necessary to raise a little an edifice of the madrasa on a platform (Borodina, 1987; fig. 4. 56).

The architect, whose name was simply Bako, entwined his name (as well as the date of construction and the name of Arslan-Khan) with epigraphic ornaments of the Minaret (Borodina, 1987). Local inhabitants believe that the architect was buried somewhere among houses of the neighboring residential quarter. Bako made a minaret in the form of a circular-pillar brick tower, narrowing upwards, of 9 meters (29.53 feet) diameter at the bottom, 6 meters (19.69 feet) overhead and 45.6 meters (149.61 feet) high (fig. 4. 55). There is a brick spiral staircase that twists up inside around the pillar, leading to the landing in a sixteen-arched rotunda - skylight, which is based on a magnificent stalactite cornice (*sharafa*). The madrasa became closely resembled the four-*iwan* mosque in plan (Gangler *et. al*, 2004).

It is not open to tourists, who can admire from a distance the calligraphy and mosaic around the drums supporting its two blue domes, but are said to be missing some of the finest ceramic decoration in Bukhara. Apart from its great size, its most notable feature is the great *pishtaq* (gateway), which is beautifully decorated with mosaic, plaster relief work and painting.

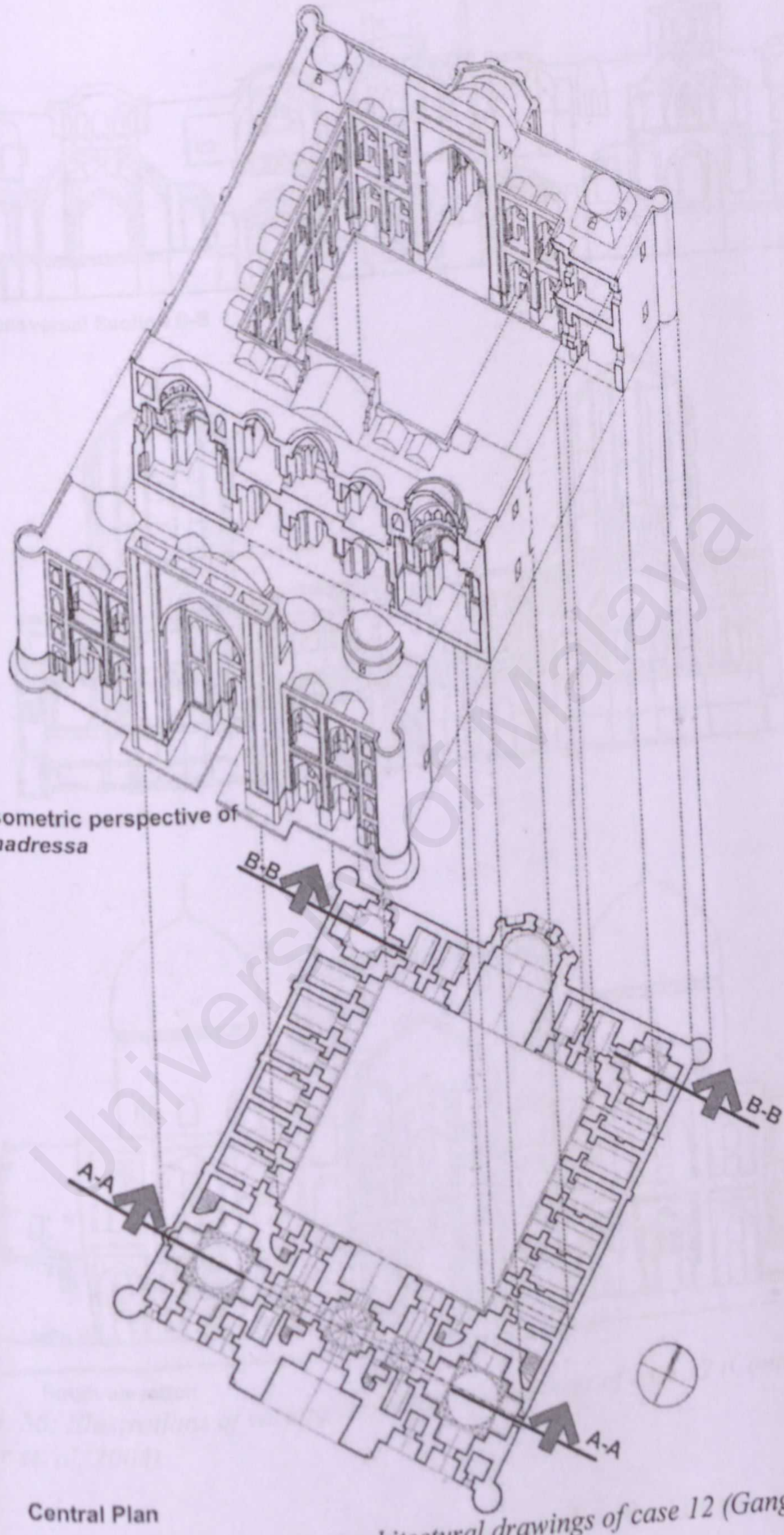
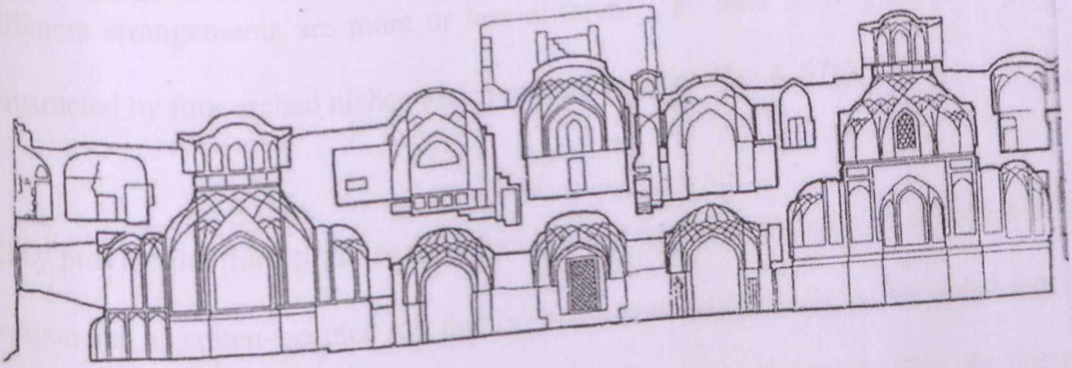
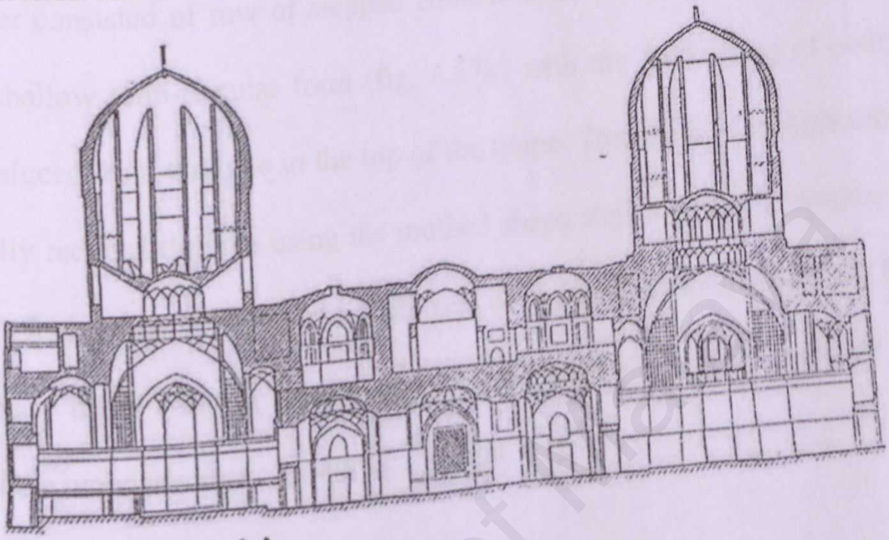


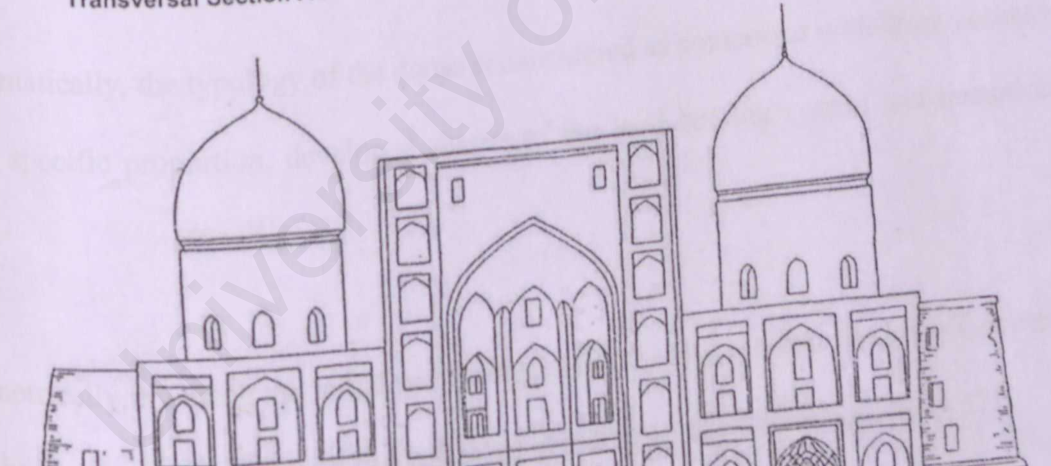
Figure 4. 55: Illustrations of various architectural drawings of case 12 (Gangler et al. 2004).



Transversal Section B-B



Transversal Section A-A



South elevation

Figure 4. 56: Illustrations of various architectural drawings of case 12 (Continued) (Gangler et. al, 2004).

***iii. Analysis of the dome Z*:** these domes chiefly ranked as the last generation of the pointed discontinuous double-shell domes in the Middle East and Central Asia. Both their external shells were built similarly together whilst their internal shells and stiffeners arrangements are more or less different. The load bearing of dome Z was constructed by four arched niches which occupy recesses (fig. 4. 57c).

They provide the transition tier from four corners to eight-pointed star, followed by an octagon and a sixteen- pointed star that is circled in towards the thirty-two sided star. Its transition tier consisted of row of stepped console spandrels (fig. 4. 57b). Its internal shell is of shallow semi-circular form (fig. 4.57k) with the thicknesses of both shells gradually reduced from the base to the top of the dome. Thickness of its high drum was also gradually reduced through using the toothed shape steps in its construction system (fig. 4. 57a). Its internal stiffeners are composed of eight radial walls which are fixed to the drum body using wooden struts and also articulated their upper parts by second typology of the wooden struts (fig. 4.57d. e.; fig, 4. 58).

Grammatically, the typology of the dome is considered as compound with drum because of its specific proportion, developed shapes of the load bearing system and transition tier.

Geometrically, by using the initial profile characteristics, its external shell is considered as a three-centered profile with the following geometrical characteristics (fig. 4.57f):

- **External shell:** $\left\{\begin{bmatrix}0\\0\end{bmatrix}, \angle 30, \begin{bmatrix}2/4ab\\1/3ab\end{bmatrix}\right\}$

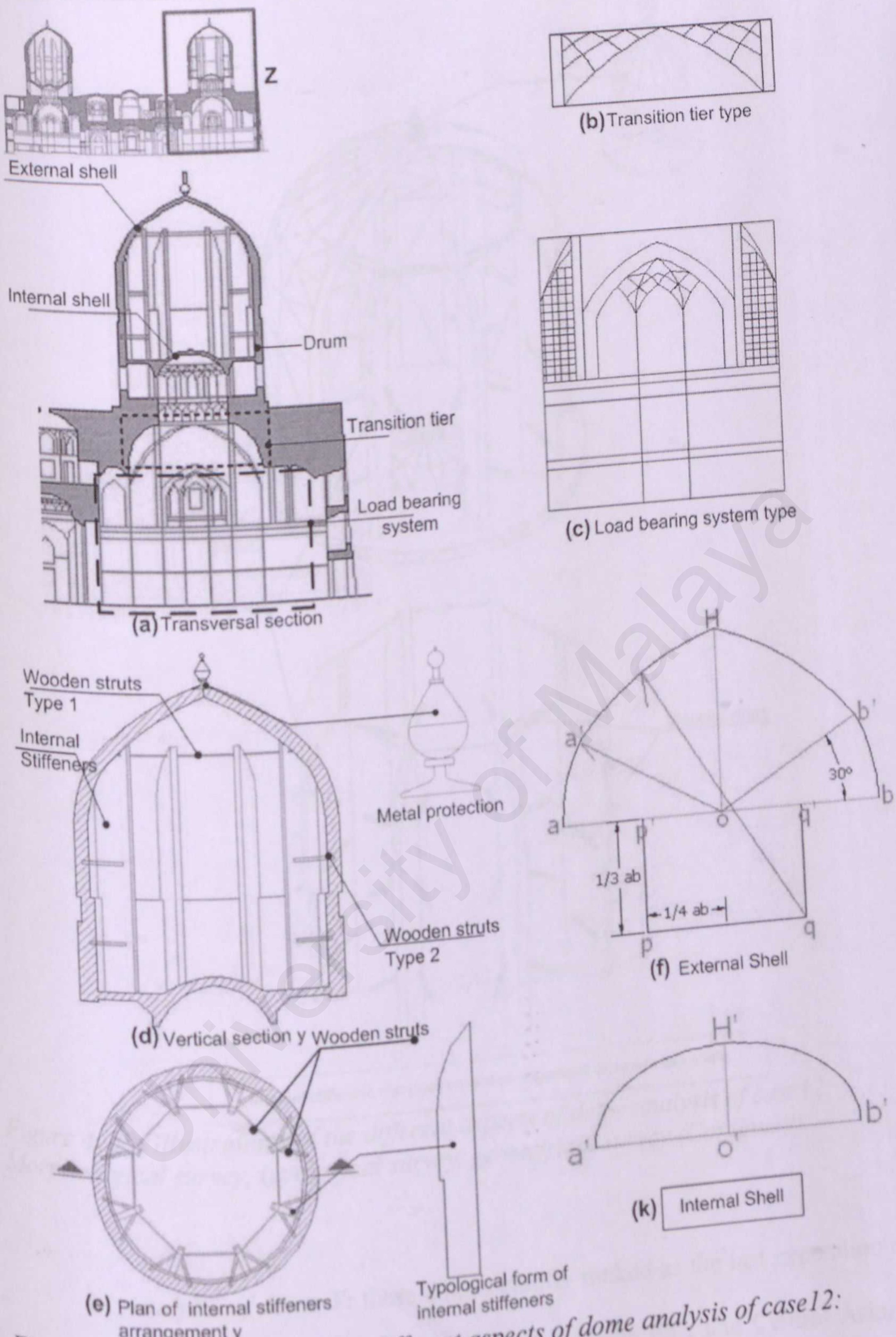


Figure 4. 57: Illustrations of the different aspects of dome analysis of case12: Morphological survey, typological survey, geometrical survey.

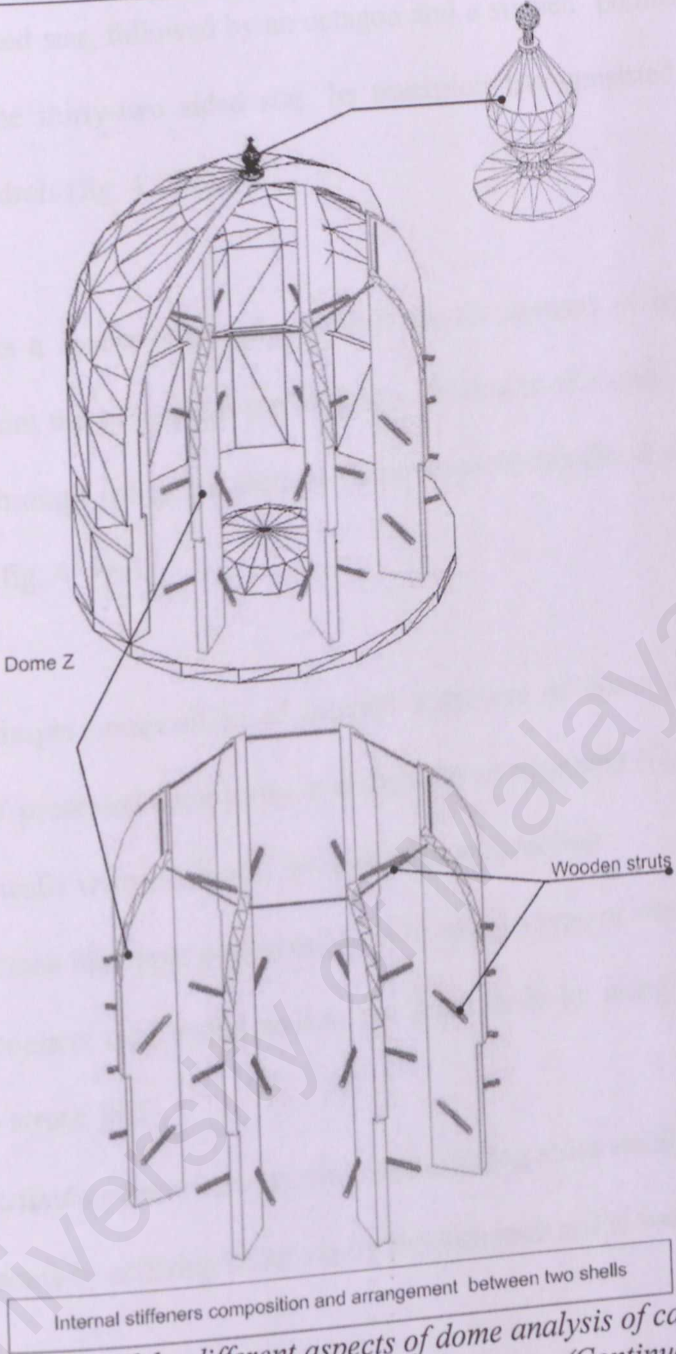


Figure 4. 58: Illustrations of the different aspects of dome analysis of case12: Morphological survey, typological survey, geometrical survey (Continued).

iv. Analysis of dome Y: these domes chiefly ranked as the last generation of the pointed discontinuous double-shell domes in the Middle East and Central Asia. Both their external shells were built similar whilst their internal shell and stiffeners' arrangements are more or less different.

The load bearing of dome Y was constructed similarly as the dome Z by four arched niches which occupy recesses (fig. 4. 59c). They provide the transition tier from four corners to eight-pointed star, followed by an octagon and a sixteen- pointed star that is circled in towards the thirty-two sided star. Its transition tier consisted of rows of stepped console spandrels (fig. 4. 59b).

Its internal shell has a saucer shape (fig. 4.59k); the thicknesses of both shells are gradually reduced from the base to the top of dome. Thickness of its high drum is also gradually reduced through using the toothed shape steps in regular distances for the structural purposes (fig. 4. 59a).

Compared to the simple composition of internal stiffeners of dome Z, the internal stiffeners of dome Y presented complexity in design and arrangement (fig. 4.59d, e.; fig, 4. 60). Eight radial walls were connected through three approaches:

1. To attach the upper part of radial walls using a type of wooden struts;
2. To connect each radial wall to the drum body by using second type of wooden struts; and
3. To articulate the whole system (for providing more stability) to the lower components by utilizing small vaults between each radial wall.

From the typological point of view, the typology of the dome is considered as compound with drum because of its specific proportion, developed shapes of the load bearing system and transition tier. Geometrically, its external shell possess a three-centered profile with the following geometrical parameters (fig. 4.59f):

- External shell: $\left\{\begin{bmatrix}0\\0\end{bmatrix},\angle 30,\begin{bmatrix}2/4ab\\1/3ab\end{bmatrix}\right\}$

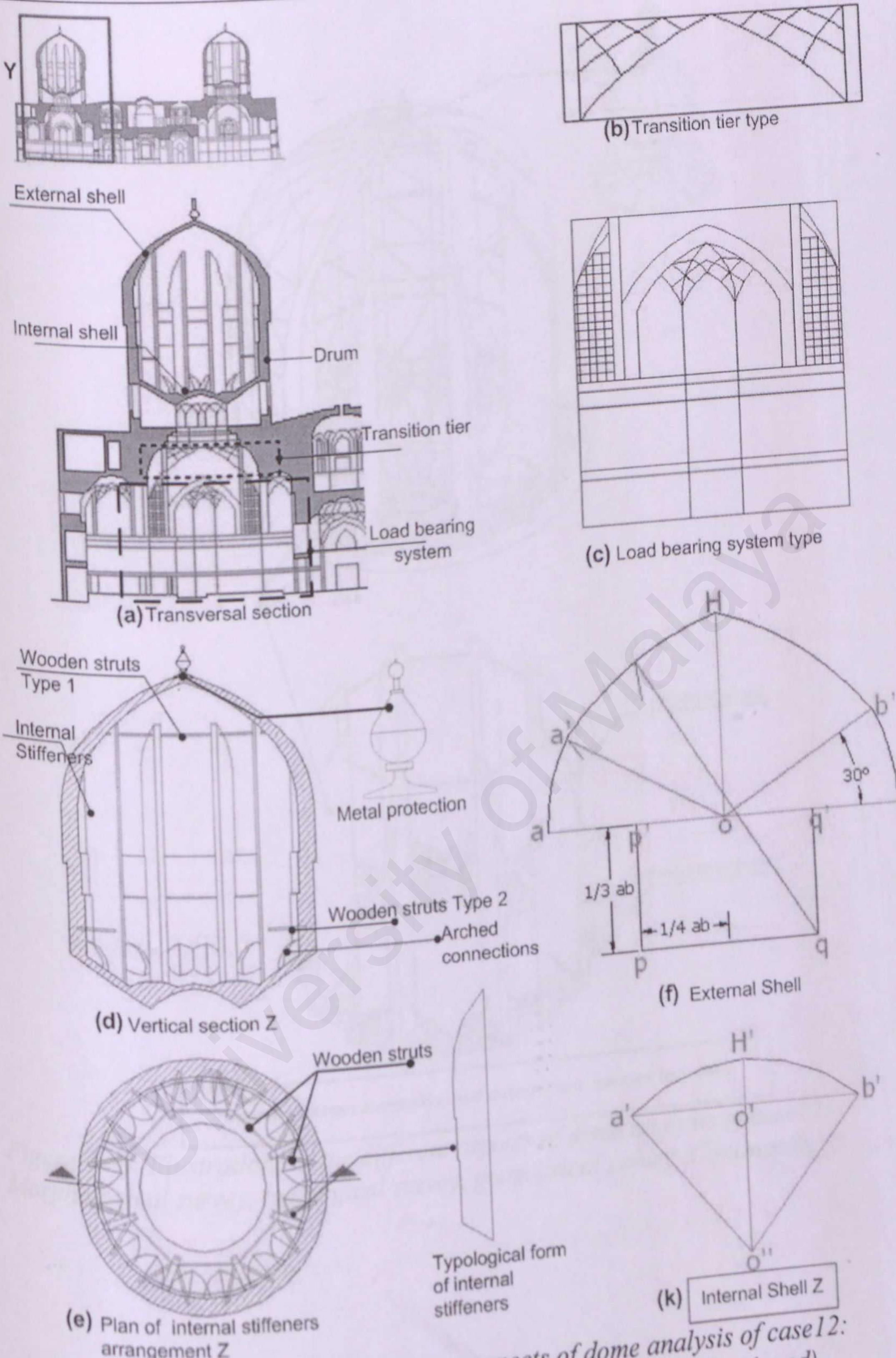


Figure 4. 59: Illustrations of the different aspects of dome analysis of case12: Morphological survey, typological survey, geometrical survey (Continued).

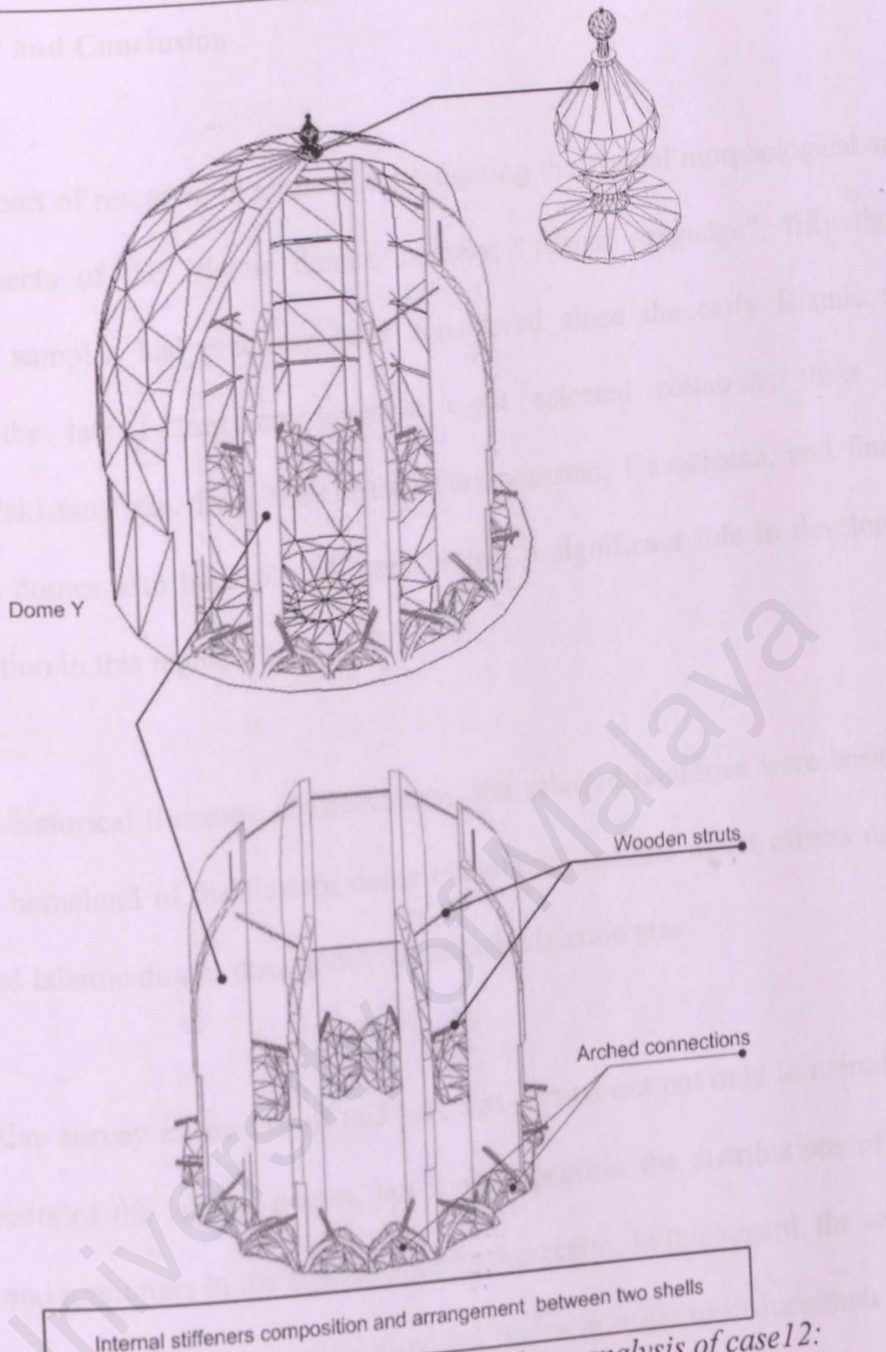


Figure 4.60: Illustrations of the different aspects of dome analysis of case12: Morphological survey, typological survey, geometrical survey (Continued).

4.4 Summary and Conclusion

In the primary part of research, in terms of investigating the typical morphological and typological aspects of the Islamic domes, namely, "*Visual language*", fifty three selected dome samples had precisely been considered since the early Islamic era through into the late Islamic era amongst eight selected countries; these are Afghanistan, Pakistan, Iran, Iraq, Uzbekistan, Turkmenistan, Kazakhstan, and finally Turkey. These domes also have played more or less a significant role in developing dome construction in this region.

Based on the historical literature considerations, the selected countries were basically considered as homeland of the Eastern dome evolutions that had direct effects on the development of Islamic domes throughout the selected Islamic eras.

The comparative survey as essence of this part was carried out not only to identify the dominant aspects of the Islamic domes, but it also specifies the distributions of these vocabularies and grammars in the studied zone in this realm. In this regard, the selected case studies are assorted in the specific provided tables in order to deduce their visual language characteristics, qualitatively. The visual languages of the Islamic domes may generally express as two general architectural expressions as follows:

- Four generic vocabularies in morphological aspects were included as the various forms of supporting system, transition tier, drum, and shell(s). In fact, the vocabulary basically deals with the models of the four generic parts of dome. It concerns such issues as their constituent forms and shapes in either the developed concept or simple concepts; and

○Two developed grammars in typological features were proposed as simple and compound. These grammars, on the other hand, relate to various systems of organizing their shells into a coherent whole within the frameworks of simple and/or compound.

Those aforementioned vocabularies and grammars were assorted in the provided tables, respectively. The provided tables were respectively filled by evaluating samples, comparatively, in each defined zone. In terms of incomplete information of samples, the sign of question mark (?) was used beside those circular signs. In order to underline the conical domes, the sign of (A) was used beside the circular sign of shell vocabulary. Each dome was comparatively analyzed according to its plans, photographs, and, whenever possible, site visits to determine the relative levels of architectonic conceptual configurations.

The results of this study indicate the existence of definite visual languages, either as development compositional feature or as simple appearance, possessing both vocabulary and grammar. As primary results of analysis, the dominant derived features of studied regions in the Middle East and Central Asia can be addressed as follows when possibilities of existence of exception samples in each region were overlooked:

- Iran: bulbous, conical, pointed;
- Iraq: conical and pointed;
- Afghanistan: pointed;
- Pakistan: semi-circular, bulbous and Mongolian;
- Uzbekistan: conical and pointed;
- Turkmenistan: conical and pointed; and

- Turkey: semi-circular and saucer.

Secondly, commonalities of the dominant morphological (vocabularies) and typological (grammars) aspects of the Islamic domes in the studied zones can be illustrated as follows[9]:

- Domes in the Turkey region consisted of whether a semi-circular or saucer shells which were rested on the *pendentives* type of the transition tier including nets of huge lateral vaults as supporting systems. Drums were not found out significantly very high and their most typical shapes recognized many-sided. Grammatically, the common identified configuration typology of the Turkish domes were simple with drum and presented neither complexity in design nor arrangements, despite their huge size and scale;
- Domes in the Iran and Iraq regions showed diversity in shapes and configurations. They consisted of two stories cube shape of load bearing systems topped with two different shapes of shells. Their external shells often appeared in three uniform features: conical, pointed, and bulbous whilst there does not exist any limitation in the diversity of internal shell formations. Both types of drums (many-sided and cylinder) were identified with variances in heights. Grammatically, the dominant composition of domes in these regions was compound with complexity in geometrical design and diversity in their arrangements;
- Domes in Pakistan and Afghanistan presented completely differences in the compositions and vocabularies. Domes in the Pakistan zone were increasingly followed the typical aspects of the Mongolian domes in India ;

[9] Refer to sub-chapter 5.3.5 under subheading distributions of four morphological features and table 5.1 for more detail.

whereas Afghani domes possess main languages' aspects of the Middle Eastern domes. Domes in Afghanistan region consisted of the pointed discontinuous double shells which were placed on the load bearing system in the square or hexagonal formations. The transition tier forms were composed of a high vaulted niche within opening frames in regular positions as well as using stepped console spandrels which were also consisting of rows of superimposed brick brackets. Use of the high cylinder drums was identified. Domes in the Pakistan region, increasingly constituted of a massive semi-circular shell which rested on vaulted niches framed with brackets as typical forms of transition tier in this region. The typical Mongolian forms were also roughly identified. The various forms of hexagonal shapes of the load bearing systems, which were flanked by massive tapper towers, are the dominant features of domes in this region. Grammatically, domes in Pakistan did not represent specific developments either in compositional grammars or vocabulary formations (except for their huge scale) whilst the domes in Afghanistan were considered as having complexity in their designs and arrangements; and finally

- Domes in Uzbekistan, Kazakhstan, and Turkmenistan were more similar compared to the previous three zones. They were either pointed or conical double-shell formations which were often constructed on the rows of stepped console spandrels and the huge cylindered drum. The dome is rested on the square shaped bearing walls including symmetrical arches. From the typological point of view, these domes presented complexity in their organization, geometrical design, scale of domes and developed shapes of the vocabularies.

In general, from typological point of view, Islamic Eastern domes consisted of the four generic components including shell, transition tier, drum, and load bearing system which had commonly been seen in the studied regions of the Middle East and Central Asian countries. These components may have different compositions over historic eras depending on the dominant styles of certain dynasties. Existing shell, transition tier, and supporting system were found obligatory whilst the drum is an optional component. Overall speaking, results of this primary analysis show that the pointed discontinuous double-shell domes were the typical configuration and include majority of domes in the Middle East and Central Asia.

In the second Part of Research, in order to define morphological, typological and geometrical prototypes of the pointed discontinuous double-shell domes and to derive their associated geometric profiles, samples of twelve cases located in Iran, Afghanistan, Uzbekistan, and Kazakhstan since 1067 A.D. (appearing primary sample of the pointed domes) until 1600 A.D. (the end of medieval Islamic era). The studied periods, dynasties, and countries are particular causes for developing of consifurations of the pointed discontinuous double-shell domes that were never surpassed in the other periods later on.

In general, the pointed discontinuous double-shell domes expose logical designs, with vigorous articulation of clear proportional distinct elements. In fact, as a result of the analysis of these case studies, the common identical components of these types of the Islamic domes are morphologically specified as the external shell (the most importance component and the most visible part of dome), high cylinder drum, internal shell, and radial stiffeners within the wooden struts for filling the empty space between two shells for integrating the whole system.

The developed initial profile explicitly represented a derivation process of the geometrical concepts of the discontinuous double-shell domes. Based on the *al-Kashi* geometrical essences, a theoretical framework was geometrically developed in order to derive the essences of the geometric syntax of the discontinuous double-shell domes designs with focused on the pointed type

For specifying the typological and geometrical aspects of the generated profiles of twelve case studies, the stages below might have been followed:

- The computation process of the samples analysis started with the generation of their both external and internal shells profiles;
- Discerning the profile geometric properties based on the defined analogical patterns: an analogical pattern of the pointed discontinuous double-shell domes is schematically designated to understand the different existent properties of such profile constitutions, i.e., mainly the locations of the centre points of the lower arcs based on certain definitions;
- Deriving the geometric parameters based on developed essences of the general profile and setting up the geometrical parameters according to their specific systems; these are the geometrical proportions of the surveyed profiles including fractions of their spans and the locations of their breaking points were deduced; and
- Re-modeling of the general profile and obtaining the common prototype of the pointed profile. In fact, the generated profile not only presents the typical configuration of the pointed typology, but it also has the potential to evolve into variations of the by using the variable values of parameters.

As results of the analysis of examples by using the developed four-centered profile, three sub-sets of the pointed profiles according to the number of their centre points have been recognized and the configured based on the proposed parametric system (which would comprehensively be elaborated and discussed in the next chapter):

- Two-centered profile (cases 2, 5 and 9)
- Three-centered profile (case 1 and 12)
- Four-centered profile (cases 3, 4, 6, 7, 8, 10, and 11)

The internal shell forms are recognized as semi-circular (cases 8, 6, and 10), semi-ellipse (cases 11, 12y, 9, and 4), pointed (cases1, 2, 3, 5, and 7), and saucer form (case 12z). On the other perspective, the presented analysis approach with its systematical presentation system not only can utilize as the syntax elaboration of the geometric arrangements of the external shell of the pointed discontinuous double-shell domes, but it also has the potential to generate and compose any sort of the pointed features.

Additionally, the three sub-sets of typologies of the pointed discontinuous double-shell domes are classified according to the variance in heights of the external shell rises; these are shallow, medium, and sharp. Usage of the initial profile based on the developed geometric system put forward more opportunities for offering a unique computational classification method for the design analysis and geometric definitions of the Eastern Domes, such as the Mongolians, one shell domes, etc.

Finally, this chapter concluded with successful applications of the proposed methods (from Chapter Three) in analysis of the selected examples generally and specifically for answering the Research questions. The comprehensive derived results, which were briefly explained in this Chapter, would extensively be clarified in detail in the next Chapter.

Chapter 5
Research Results and Discussions

5.1 Introduction

This research was carried out with the main objectives of assessing firstly the formal architectural language of the Islamic domes including their vocabularies and secondly grammars in the Middle East and Central Asia. Then, it focused on the detail analogical examination of the pointed discontinuous double-shell domes, that is, their morphology, typologies, geometrical design, and finally structural characteristics.

This chapter includes the whole results derived from both Parts of Research; firstly, fifty three samples selected from eight countries had been investigated typologically and morphologically. As a result, the common prototype of Islamic domes generally revealed whether as one or two shells which are placed on a high cylinder drum, namely, "top of the dome". They are rested on the bottom components including the squinches and a load bearing system. The supporting system consists of compositions of the positive and negative vaulted-tunnels which are arranged symmetrically surrounding on a central plan.

In the second part of Research, Twelve case studies had been selected from the four countries; these are Iran, Afghanistan, Kazakhstan, and Uzbekistan. These regions are included the majority of the pointed dome typologies from the early Islamic era through the late Islamic period.

The present research involved a new framework that not only defined systematically the morphological formations and the derivation of common typologies of the pointed discontinuous double-shell domes, but also it offered the analytical understanding of the newly geometrical language that might have appeared in the designs of other types of dome over historic period.

5.2 Historical Outlines of Developments of the Eastern Domes in Historical Architecture

The dome is a roof, the base of which is a circle, an ellipse, or a polygon, and its vertical section a curved line, concave towards the interior. Hence domes can be called circular, elliptical or polygonal, according to the figure of its base. The most usual form is the spherical, in which case its plan is a circle and/or the section a segment of a circle. The cross-sections or external shapes of domes, especially, the Eastern ones are sometimes semi-elliptical, pointed, and bulbous and so on; whereas the Western domes often appeared in either curves of contrary flexure or bell-shapes.

Generally, one of the main problems of dome construction was the transition from a square plan into a circular base of dome. Usually, there was an intermediary octagonal area from which it is easier to convert to a circular area although there is still the problem of converting from square to octagon base of shell. Two main methods were adopted, *squinches* and *pendentives*, which are considered as the essential difference between the Eastern and Western domes.

The *squinch* is a mini-arch which is used to bridge a diagonal corner area; whereas a *pendentive* is an inverted cone with its point set low down into the corner and its base at the top providing a platform for the dome. *Squinches* are the main method of transition tier construction techniques in the Eastern architecture whilst *pendentives* spread after the sixteenth century in the Ottoman and the Western architecture. Nevertheless, the symbolic meanings associated with domes are considered as fundamental causes for the rapid development of this architectonic item entirely between both Eastern and Western architectures.

On the historical point of view, the Eastern dome seems to be have developed as roofing for circular mud-brick huts in the ancient Mesopotamia and Asur about 6000 years ago. In the 14th century BC the Mycenaean Greeks erected tombs topped with steep corbelled domes in the shape of pointed beehives (tholos tombs). Otherwise, the dome was not important in ancient Greek architecture. The wooden domes were another common dome techniques in the Near East, specially, in Syria and Palestine.

Beyond the historical texts, the dominant features of the primary samples of Eastern domes are predominantly exposed in the configuration of the primary samples such as Sanchi stupa (third E.B.C) in India, Nyssa dome hall (first century A.D.) in Turkmenistan, the Basilica of Hagia Sophia in Turkey, and the Sassanian palace of Ardeshir in Iran (240 A.D.). In fact, the Middle East and Central Asia can be considered as a homeland of the appearing and evolving Eastern domes.

After the coming of Islam and introduction of using the wooden Dome of the Rock (621 A.D.), thousands of masonry domes were built in the Middle East and Central Asia. Furthermore, the influence of the Islamic domes made itself felt in the Western architecture as late as the nineteenth century.

During various Islamic eras, the most dominant dynasties that had critical roles in developing domes in such a way that every dynasty had improved upon the previous technical methods and prompted new artistic qualities, without destroying the older aspects. They can be named, respectively as follows: (fig.5.1): the Samanids (819-1005A.D.), Seljuks (1038-1194 A.D.), Ilkhanids (1256-1353 A.D.), Timurids (1370-1506 A.D.), Saffavids (1501-1732 A.D.), and Shaybanids (1503- 1800 A.D.).

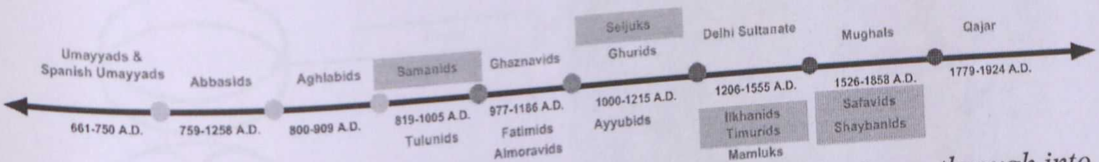


Figure 5.1: Illustration of the distinct dynasties from the early Islamic era through into the late Islamic era. The highlighted dynasties are studied in this Research.

Compositionally, the dome can be considered as a structural consonance and a hierarchy of ordered parts, that is, the relationship between the internal space and structural mass and/or positive-negative spaces. Morphologically, the Eastern domes consist of the four generic features, called "*vocabularies*": load bearing system, transition tier, drum, and shell(s) (fig. 5.2).

- ***supporting system:*** these are the essential structural system which must fulfill the requirements of the building's statics by transferring the load to the ground;
- ***Transition tier:*** the structural feature designed to take the horizontal thrust of the dome and also should be able to transfer it to the lower bearing system. This architectural device can be constructed based on the two main methods: *pendentives* from the Byzantine architecture and *squinches* from the Sassanids Empire;
- ***Drum:*** is often a cylinder form on which the external shell is rested on; and finally
- ***Shell(s):*** the special sacred space was provided by the shell(s). In fact, the architectural item which was often used synonymously in different regions. In fact, it is a total reflection of the dome dynamism, in particular, at various Islamic periods.

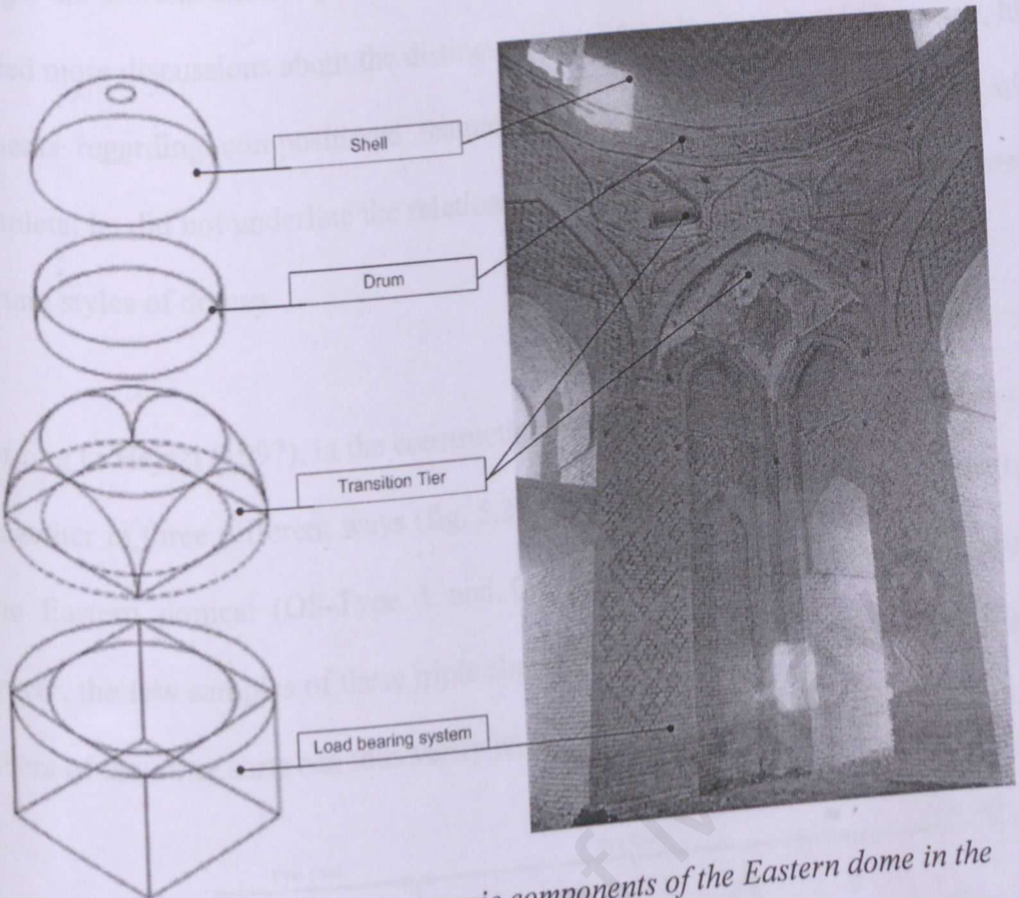


Figure 5.2: Illustration of the four generic components of the Eastern dome in the Middle East and Central Asia.

By the end of 18th century, the innovative approaches in the constructions of Islamic dome styles went into decline and the number of domes considerably decreased with the fall of the Saffavids and Shaybanids in the Middle East and Central Asia, although the dome survived longer in India (the late Mughal architecture) up to the end of late Islamic era.

The works of Memarian (1987), Memarian and Pirniya (2003), Pirniya and Bozorgmehri (1992), Poole and Giambo (2007), and Hejazi (1997) may be highlighted to indicate the general features and historical considerations regarding the Eastern domes' general features and typologies; however these often mainly focused on the specific region of the Middle East and Central Asia such as Iran, Azerbaijan, Uzbekistan and so on, or concentrated only on certain features of domes.

Amongst the aforementioned previous researches, works of Hejazi (1997) increasingly involved more discussions about the distinct aspects of the Eastern domes; however, his arguments regarding compositional features of the Eastern domes in detail is still incomplete; he did not underline the relationship between historic eras and development of certain styles of domes.

According to Hejazi (1997), in the construction of the Eastern domes, the shell(s) can be put together in three different ways (fig. 5.3). These include one shell (the earliest type of the Eastern domes: (OS-Type 1 and OS-Type 2), two shells and three shells. However, the few samples of these triple shells that emerged in comparison to the large numbers of the other sorts can thus verify its origin from the double-shell domes.

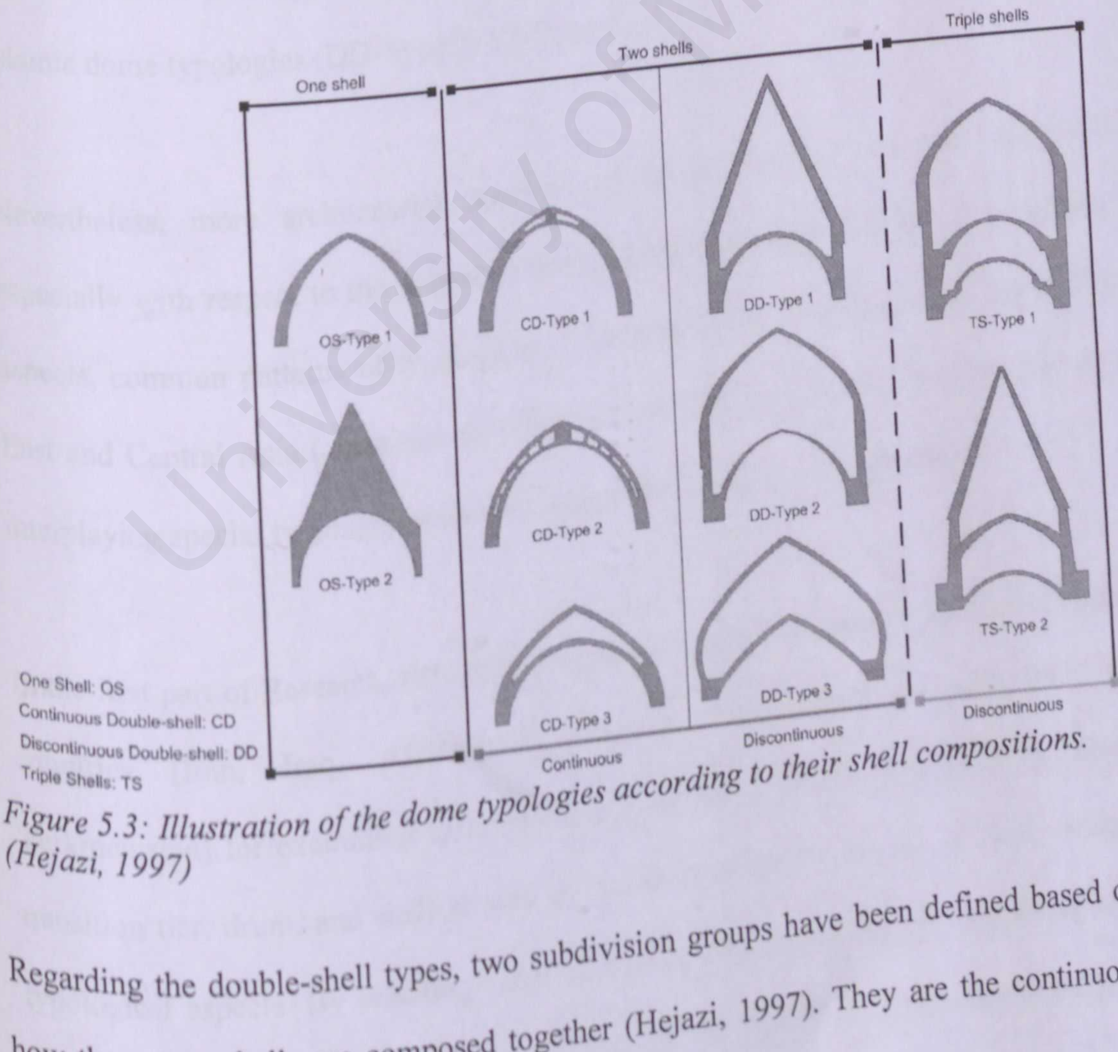


Figure 5.3: Illustration of the dome typologies according to their shell compositions. (Hejazi, 1997)

Regarding the double-shell types, two subdivision groups have been defined based on how these two shells are composed together (Hejazi, 1997). They are the continuous and the discontinuous groups.

In the continuous double-shell domes, sometimes there exists no considerable distance between the shells (CD-Type 1), or they are connected by brick connectors (CD-Type 2), but very often the distance between these shells is small (CD-Type 3). It could thus be said that the continuous two shell domes are called 'evolving' from the one shell dome to the two shells domes in the development of Islamic dome architecture. Constructions of the one shell domes, however, were continued up to the late Islamic era.

In the discontinuous double-shell domes, there are considerable distances between the two shells. The discontinuity may start either from the base (DD-Type 3) or from the top of the drum (DD-Type 1 and 2). It is considered higher than the other types of the Islamic dome typologies (DD-Type 2; TS-Type 1).

Nevertheless, more architectural concepts of Eastern domes are still uncertain; especially with respect to the crucial problem of characteristics of their morphological aspects, common patterns of typological characteristics of these domes in the Middle East and Central Asia (since the early Islamic until the late Islamic epochs), and also interplaying special typologies with the compositions of dome components.

In the first part of Research, fifty three samples of domes had been selected from eight countries (Iran, Iraq, Afghanistan, Pakistan, Uzbekistan, Kazakhstan, and Turkmenistan) for examining their morphological aspects such as, supporting system, transition tier, drum, and shell as well as for the broader definitions of their common typological aspects. By selecting these examples, Research aimed at answering three essential questions (Objectives i, ii, and iii) about Islamic domes from the early Islamic era until the late Islamic era:

- What are the common morphological features (or vocabularies) of the Eastern domes in the different regions of the Middle East and Central Asia?
- What are the typical typological commonalities (or compositional grammars) of the Islamic domes in the different regions of the Middle East and Central Asia?
- How important are the distributions and emphases of these aspects throughout those certain regions?

The second part of research concentrated on the detailed estimations of the pointed domes as a sub-type of the discontinuous double-shell domes. Historically, a pair of the eleventh century Iranian tomb towers found out as the earliest sample of such domes in such a way that its internal and external shells embrace similar thickness and also were completely independent of one another.

Later on, after severe degeneration of architecture caused by several Mongol invasions and ravages of their successor Timur (that produced a gap in the dome construction evolution), the material culture of the Middle East and Central Asia flourished again by appearing the Ilkhanids (in Iran) and Timurids (in Uzbekistan) (Grabar, 2006). In this regard, the dome over the Sultan Bakht Aqa mausoleum in Isfahan (1351-52 A.D.) is the earliest complete example of the pointed discontinuous double-shell dome in which its internal and external shells have substantially constructed in the different profiles with radial stiffeners.

Overall speaking, the pointed typology historically contains the majority of the discontinuous double-shell domes surround the Middle East and Central Asia. These pointed double-shell domes were commonly placed over mausoleums, mosques, and *madrasas*. The investigations of exhaustive configurations of the pointed dome typology demonstrated the superior developments of their architectural conceptualism. In fact, the pointed discontinuous double-shell domes can be described as the result of the continuous evolution of the Islamic domes since the early Islamic era (ca. 1067 A.D.) till the early late Islamic era (ca. 1600 A.D.) when the bulbous domes became the dominant typology in Iran and nearby areas.

Despite several existing studies about Islamic domes and their relative meanings, the pointed discontinuous double-shell domes have still had unknown architectural morphology, typology, geometrical contexts and structural characteristics.

By selecting those twelve pointed discontinuous double-shell domes from four countries including Iran, Afghanistan, Kazakhstan, and Uzbekistan, Research aimed to answer the following four essential questions (Objectives iv, v, vi, vii):

- What are the common morphological features of the pointed discontinuous double-shell domes in the Middle East and Central Asia as major style of Islamic domes in the Middle East and Central Asia?
- What are the common typological aspects of such domes in this region?
- What are the common geometrical prototypes and geometrical traits of this type of Eastern domes in the Middle East and Central Asia?
- Where are the vulnerable parts of such domes, structurally?

In general, the pointed discontinuous double-shell domes were built based on specific geometric formula and special structural compositions. In order to analyze their geometrical design, it seemed necessary to consider briefly the relationship between historic geometry and dome design for generating a proper geometrical method (Objective v). From another perspective, examination of the historic geometric formulations and their impact, especially in the Islamic dome conceptualism entails a procedure which can demonstrate a close collaboration between the mathematicians and architect-artisans.

5.3 Common Morphological Features of Eastern Domes in the Middle East and Central Asia

The earliest dome samples utterly revealed the lack of their non-developed form Also, they have not presented whether specific geometrical design (certain proportions) or advance configuration before the coming of Islam. Nevertheless, the dominant growth in the dome architecture occurred with the appearances of both *squinches* in Iran and *pendentives* in Turkey in the Middle East and Central Asia before the coming of Islam (fig. 5.4).

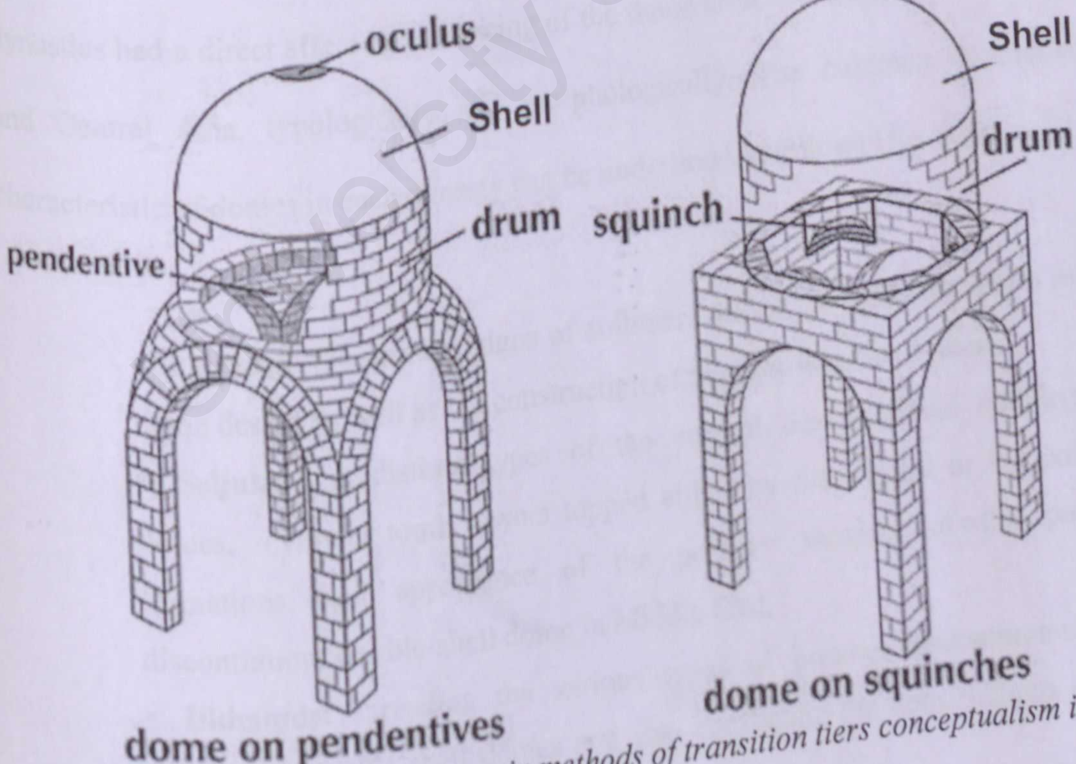


Figure 5.4: Illustration of the two main methods of transition tiers conceptualism in dome constructions.

After the coming of Islam, two essential occasions significantly influenced the dome movements in this specific boundary:

1. The contributions of mathematicians who involved for formulating special proportional approaches, not only in the dome design, but also in vault and arch constructions[1]. In fact, the Islamic mathematicians such as al-Khorezmi, al-Fargani, Ibn-Sino, Abu Sahl al-Quhi , Abu'l- Wafa Buzjani , and Ghiyath al-Din Jamshid Kashani played the significant role in presenting geometrical approaches and understanding the differences between exact and approximate calculation methods. Nevertheless, the *al-Kashi* geometrical principles had widely been used for practical purposes in the medieval Islamic era than the other;

2. Appearing of various dynasties triggered technical innovations and developments of the specific architectonic concepts and styles;

On the other hand, the architectural movements during the following highlighted dynasties had a direct affect on enhancing of the dome structuralism in the Middle East and Central Asia, typologically and morphologically. The common architectonic characteristic of domes in each dynasty can be underlined as follows (fig. 5.5):

- **Samanids**: the primary signs of collaboration of the mathematicians in the dome design as well as the construction of the semi-circular domes;
- **Seljuks**: the distinct types of the conical discontinuous double-shell domes, cylinder tomb towers topped either by the conical or the pointed formations, and appearance of the primary samples of the pointed discontinuous double-shell dome in Middle East;
- **Ilkhanids:** spreading the various types of pointed discontinuous and continuous double-shell domes and also continuing the constructions of the conical domes;
- **Timurids:** developing the geometrical and construction properties of the pointed discontinuous double-shell domes, the dominant collaborations of the

[1] Refer to sub-chapter 3.3.2 on the historical background of the roles of Mathematicians in the dome design for more information.

celebrated mathematicians in the dome design, and appearances of the distinct triple-shell domes (as a result of developing structural and architectural knowledge);

- **Saffavids:** appearing of the diverse types of bulbous domes (named in some literature as "*onion shapes*"), continuing construction of the pointed formations, ending the construction of conical domes, finally, ending up evolution of the Islamic domes in the Middle East and Central Asia; and
- **Shaybanids:** continuing the construction of the pointed discontinuous double-shell domes and ending the evolution of domes in the Central Asia.

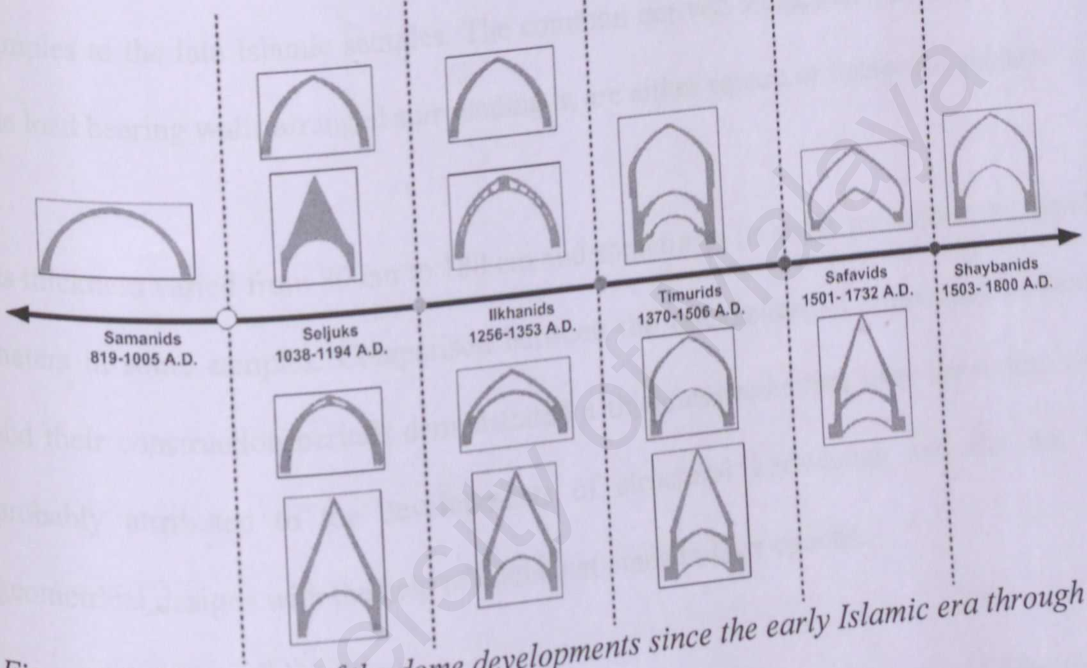


Figure 5.5: Illustration of the dome developments since the early Islamic era through into the late Islamic era.

Although these dynasties had major influence on their architectonic conceptualisms and configurations, but the role of themes of vernacular architectures and their regional agreements cannot be overlooked.

To sum up, as results of analysis of fifty three samples in the four studied zones, the common morphological features or vocabularies (shell(s), drum, transition tier, and supporting system) and their distributions over various Islamic eras in the Middle East and Central Asia are comprehensively clarified in the following sections.

5.3.1 Supporting System

The main body of dome consists of the spatial formation of its central plan which may have one, two or three opened sides. In fact, its architectonic concept is composition of positive and negative arches which are set out symmetrically surrounding a central plan. Architecturally, it is a configuration of the solid walls with whether blind arches or vaults which their arrangements have likely been developed from the early Islamic samples to the late Islamic samples. The common derived shapes of central plan, with the load bearing walls arranged surrounding it, are either square or octagonal shapes.

Its thickness varied from 80 cm to 180 cm and sometimes its value reached more than 2 meters in some samples. Comparison between the thicknesses of supporting systems and their construction periods demonstrated a thickness reduction over time; this was probably attributed to the developments of structural knowledge and the use of geometrical designs with the help of mathematicians in later epochs.

Figure 5.6 illustrates the various shape- patterns deduced from analysis of fifty three samples. Conceptually, a supporting system of Eastern domes consists of two spatial types: positive and negative shape patterns due to the structural requirements of the dome system. Positive shape patterns are dedicated to the composition of projected blinded arches and solid walls; whereas negative shape patterns (which associated with the same shape of positive shape) exposed setting of the opening sides surrounding a central plan. Nevertheless, arches and solid walls were considered as initial shapes of the load bearing systems.

Geometric proportion of the majority of samples was generally 10/11 which indicated the proportion of width to length of surrounding walls, except for: (pp-5, np-5) and (pp-9, np-9). The common derived shape patterns of those studied regions can be addressed as follows:

- Iran: (pp-1, np-1), (pp-2, np-2), (pp-3, np-3), (pp-4, np-4), (pp-5, np-5), (pp-11, np-11);
- Iraq: (pp-1, np-1), (pp-5, np-5), (pp-6, np-6);
- Pakistan: (pp-1, np-1), (pp-5, p-5), (pp-6, np-6), (pp-9, np-9);
- Afghanistan: (pp-1, np-1), (pp-5, np-5), (pp-8, np-8), (pp-9, np-9), (pp-11, np-11);
- Uzbekistan: (pp-1, np-1), (pp-8, np-8), (pp-10, np-10); and
- Turkemanistan: (pp-6, np-6), (pp-7, np-7), (pp-8, np-8).

The setting of the positive and negative shape patterns, which are located surrounding the central plan, chiefly varied from the early Islamic through into the late Islamic era, because of whether developing structural knowledge or involving specific patrons.

Deriv P	np- 8	pp-9 np- 9	pp-10 np- 10	pp- 11 np- 11
				●
R		●		
Af		●		●
U			●	
Turk				

Seljuk

Tim

Compositionally, the *mihrab* often place in blind wall and the main entrance arranged exactly in front of it. Another two sides of the dome chamber can embrace symmetrically whether openings or blind walls or composition of both (fig. 5.7). Nevertheless, the dome halls of the early Islamic samples often have only an entrance.

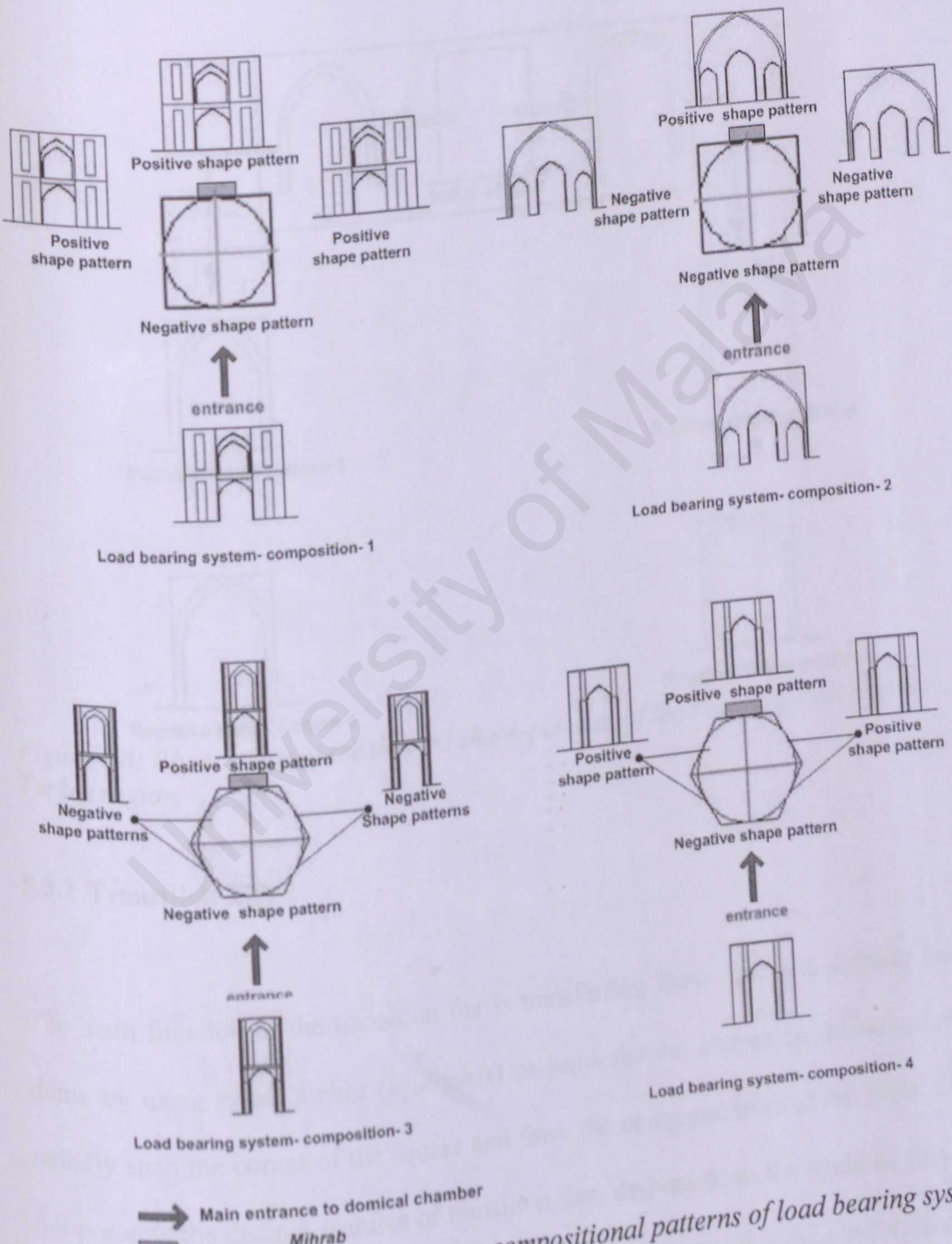


Figure 5.7: Illustrations of the common compositional patterns of load bearing systems surrounding central plans.

In terms of Turkey region, the initial shapes consisted of either a gothic pointed or a semi-circular arch composed with solid walls. The negative shape patterns 1 and 2 were identified only on the *mihrab* wall side and three sides almost always have positive shape-patterns (fig. 5.8).

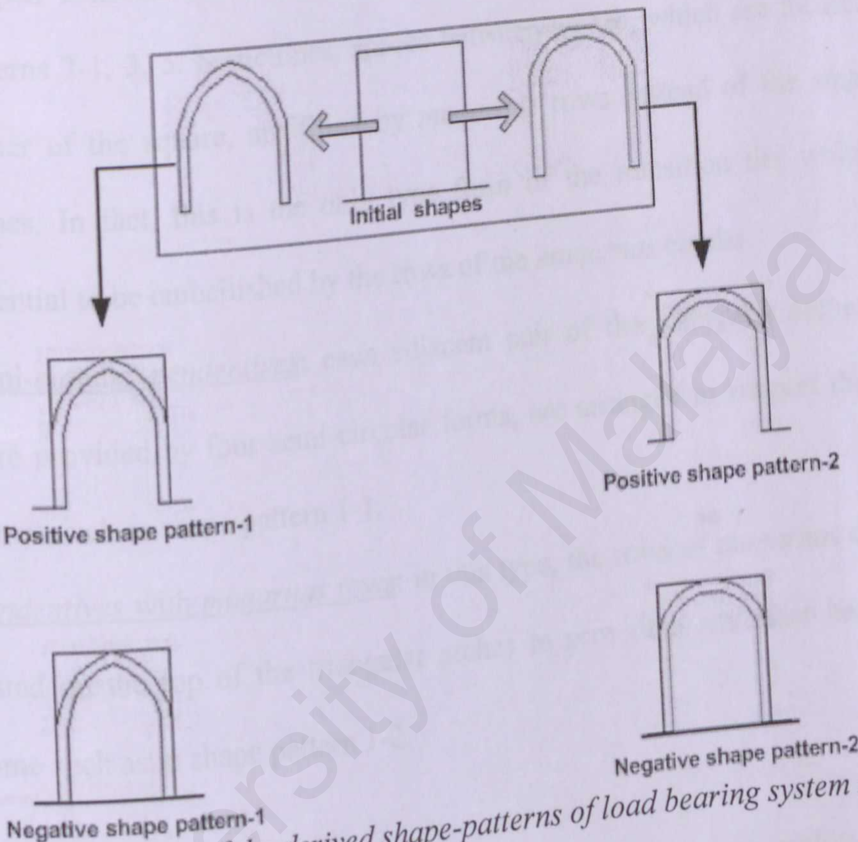


Figure 5.8: Illustrations of the derived shape-patterns of load bearing system in the Turkey region.

5.3.2 Transition Tier

The main function of the transition tier is transferring from square to circular base of dome by using either arches (*squinches*) or semi-circular shapes (*pendentives*) which radially span the corner of the square and form the octagonal base of the shell[2]. Figure 5.9 presents the distinct features of transition tiers derived from the study of fifty three samples. The common identified types of this component are addressed as follows:

[2] Refer to sub-chapter 2.5.2 on dome's base: transition tier for more information.

- Net-vaulting *squinch*: composed of row(s) of arches which are almost always framed by superimposed brick brackets. They are the simplest type of transition tier such as shape patterns 3-1, 2, 3.
- Console mini-arches or *squinch*: These are arranged gradually together as stepped consoles based on the essence meaning of *squinch*[3] such as, shape patterns 2-1, 3, 5. Sometimes, spaces between arches, which are located at the corner of the square, are filled by *muqarnas* rows instead of the small scale arches. In fact, this is the only type form of the transition tier which has a potential to be embellished by the rows of the *muqarnas* combs.
- Semi-circular *pendentives*: each adjacent pair of the triangular arches, which were provided by four semi-circular forms, are arranged to support the base of domes such as shape pattern 1-1.
- *Pendentives* with *muqarnas* rows: in this type, the rows of *muqarnas* combs are rested on the top of the triangular arches to provide a smoother base for the dome such as in shape pattern 1-2.

In general, shape patterns 1, TT 1-1, and TT 1-2 are the common prototypes of the transition tier in the Turkey region. Shape patterns TT 3, TT 3-1, 2, and 3 are often identified in the Iran, Iraq, Pakistan, Turkmenistan, and Uzbekistan regions. Shape patterns TT-2, TT 2-1, 2, 3, 4, and 5 are the common prototypes of this component in Iran, Afghanistan, Pakistan, Uzbekistan, and Turkmenistan.

Comparing the date of their constructions with the shape patterns revealed that the transition tier configurations chiefly evolved since the early Islamic era through the late

[3] Refer to sub-chapter 2.2.2 on the difference characteristic between the Eastern and Western domes for more information.

Islamic periods. The shape pattern TT-3 is the common feature of the early and medieval Islamic periods whilst the shape pattern TT-2 is the common figure of this component from the late medieval Islamic until the late Islamic era. No specific difference, however, has been recognized in developing the shape pattern TT-1 during the various epochs in Turkey.

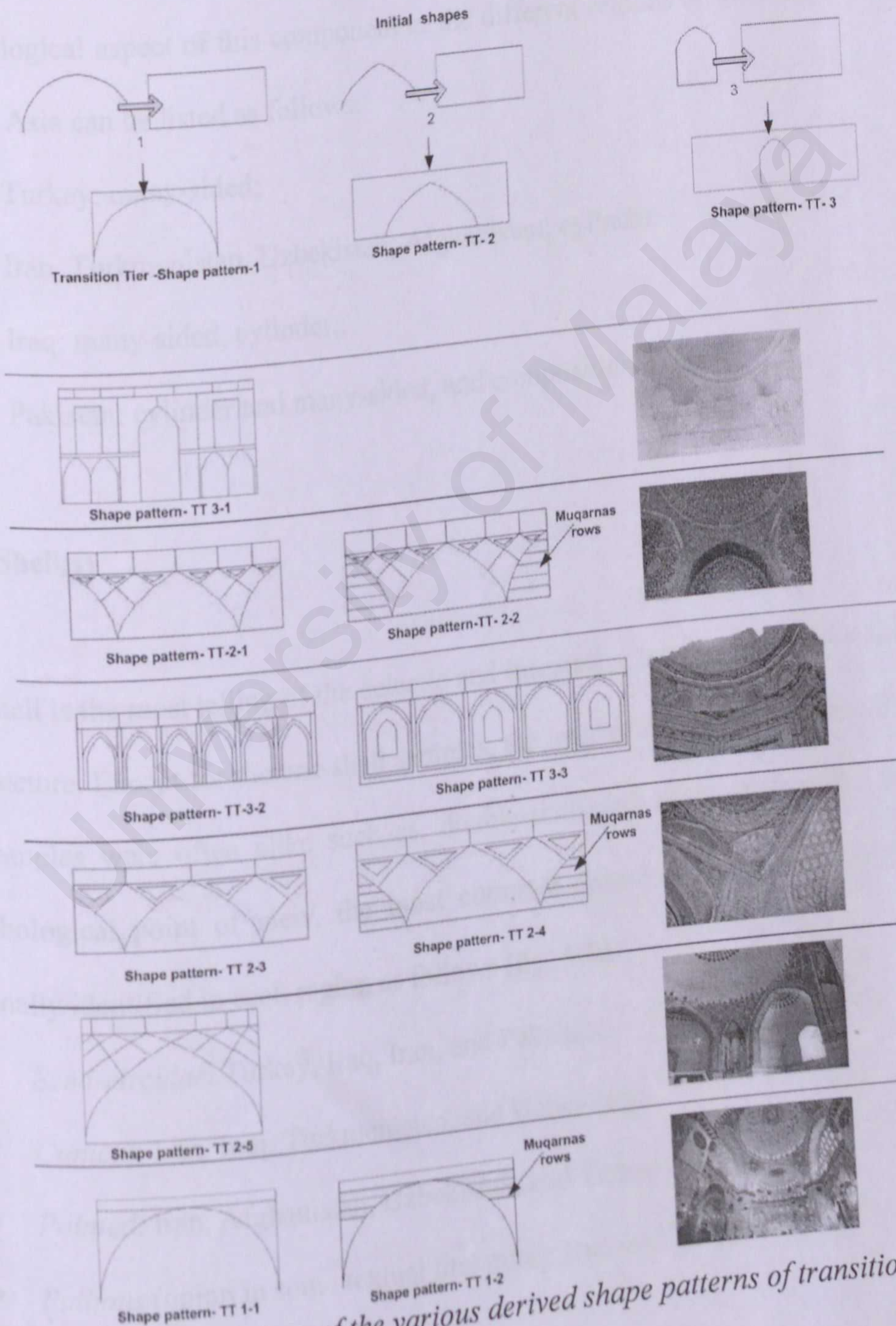


Figure 5.9: Illustrations of the various derived shape patterns of transition tier.

5.3.3 Drum

Considerable thought and effort were often given by designers to make the building as high as possible through using the three kinds of drum including many-sided, cylinder, and composition of both. In fact, it is the only component of the dome to have opening windows in order to provide lighting for internal space. Nevertheless, the common morphological aspect of this component in the different regions of the Middle East and Central Asia can be listed as follows:

- Turkey: many-sided;
- Iran, Turkmenistan, Uzbekistan, Afghanistan: cylinder;
- Iraq: many-sided, cylinder,;
- Pakistan: cylinder and many-sided, and composition of both.

5.3.4 Shell(s)

The shell is the most telling of the eclectic and integrative nature of the dome in Islamic architecture. Except for the one shell samples, the interior and exterior shells of most of the samples were often alike such as, double-shell and triple-shell cases. From the morphological point of view, the most common shapes of the external shell were regionally identified in each region as follows (fig. 5.10):

- *Semi-circular*: Turkey, Iraq, Iran, and Pakistan;
- *Conical*: Iran, Iraq, Turkmenistan, and Uzbekistan;
- *Pointed*: Iran, Afghanistan, Uzbekistan, and Turkmenistan; and
- *Bulbous* (onion in some textual literature): Iran and Pakistan.

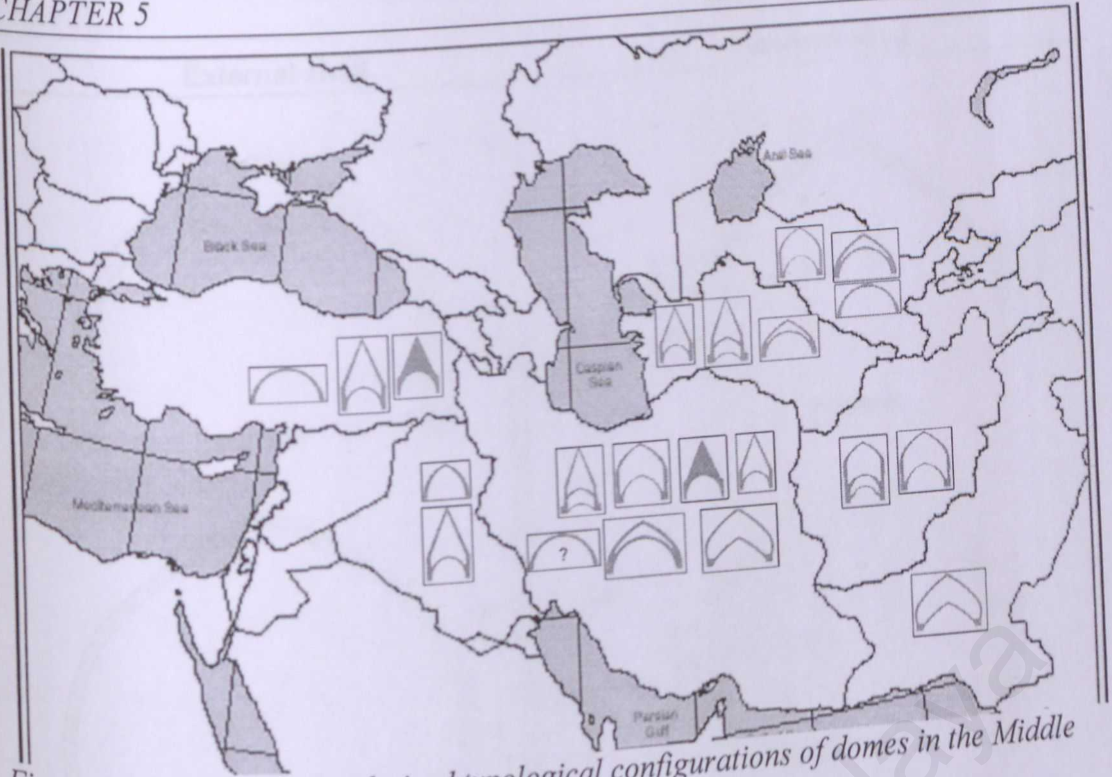


Figure 5.10: The common derived typological configurations of domes in the Middle East and Central Asia.

Note that the internal shell, which was considered the dominant feature of double-shell domes, rarely shared similarity. Its configuration was strongly affiliated with the form external form of the shell due to the need for providing structural stability of the whole system. Anyhow, the most common prototypes of the internal shell formations were recognized as semi-circular (saucer shape), pointed, and ribbed pointed. Figure 5.11 exhibits the most common possibilities of the typical compositions of external and internal shells in the double-shell samples.

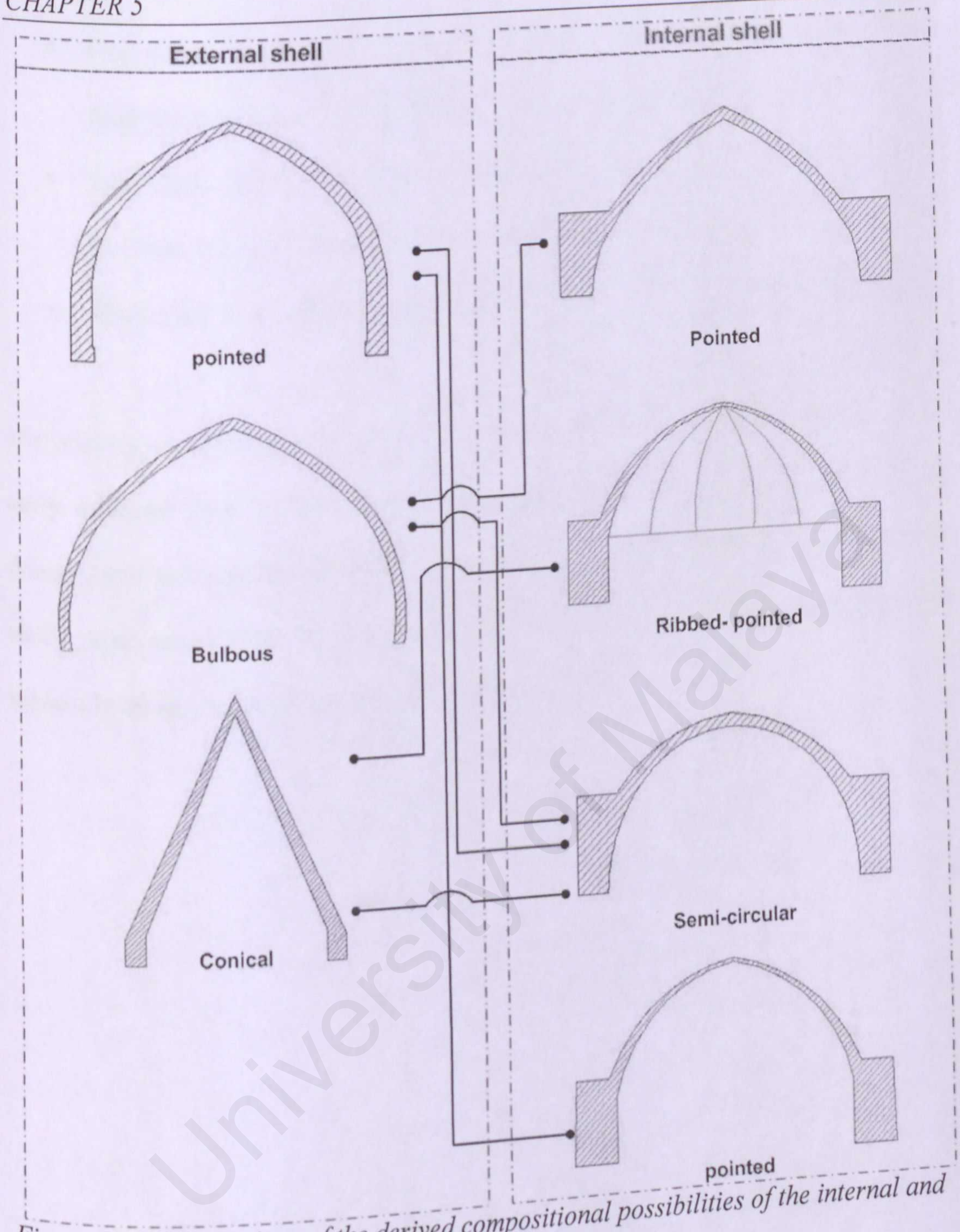


Figure 5.11: Illustrations of the derived compositional possibilities of the internal and external shells in the discontinuous double-shell domes.

Compositionally, two major typologies have been recognized based on the how these shells were composed together: one shell and double-shell. The few numbers of triple-shell verify their origin as a subdivision of the double shells in such a way that one shell almost always played either a decorative or structural role.. The common shape patterns of the various shell configurations in the Middle East and Central Asia can regionally be listed as follows (fig. 5. 12):

- One shell: Iran (OS-1, 2, 3), Iraq (OS-4 ,2), Pakistan (OS-3), Turkey (OS-3), Afghanistan(OS-1, 2), Uzbeksitan (OS-3), Turkemenistan (OS- 4, 1);
- Two shells: Iran (TS-1, 2, 3), Iraq (TS-3), Afghanistan (TS-1), Pakistan (TS-1, 2), Turkmenistan (TS-1, 3), and Uzbekistan (TS-1, 3);and
- Three shells: Iran (THS-1, 2), Afghanistan (THS-1), and Turkmenistan (THS-2).

Historically, one shell domes are the typical shape of domes in the early Islamic and the early medieval eras, whereas the double shells are the general configuration of the domes from the medieval until the late Islamic eras in all studied regions. The triple shells were rarely seen in the Timurid era when construction of domes reached its highest level and was never surpassed in any period later.

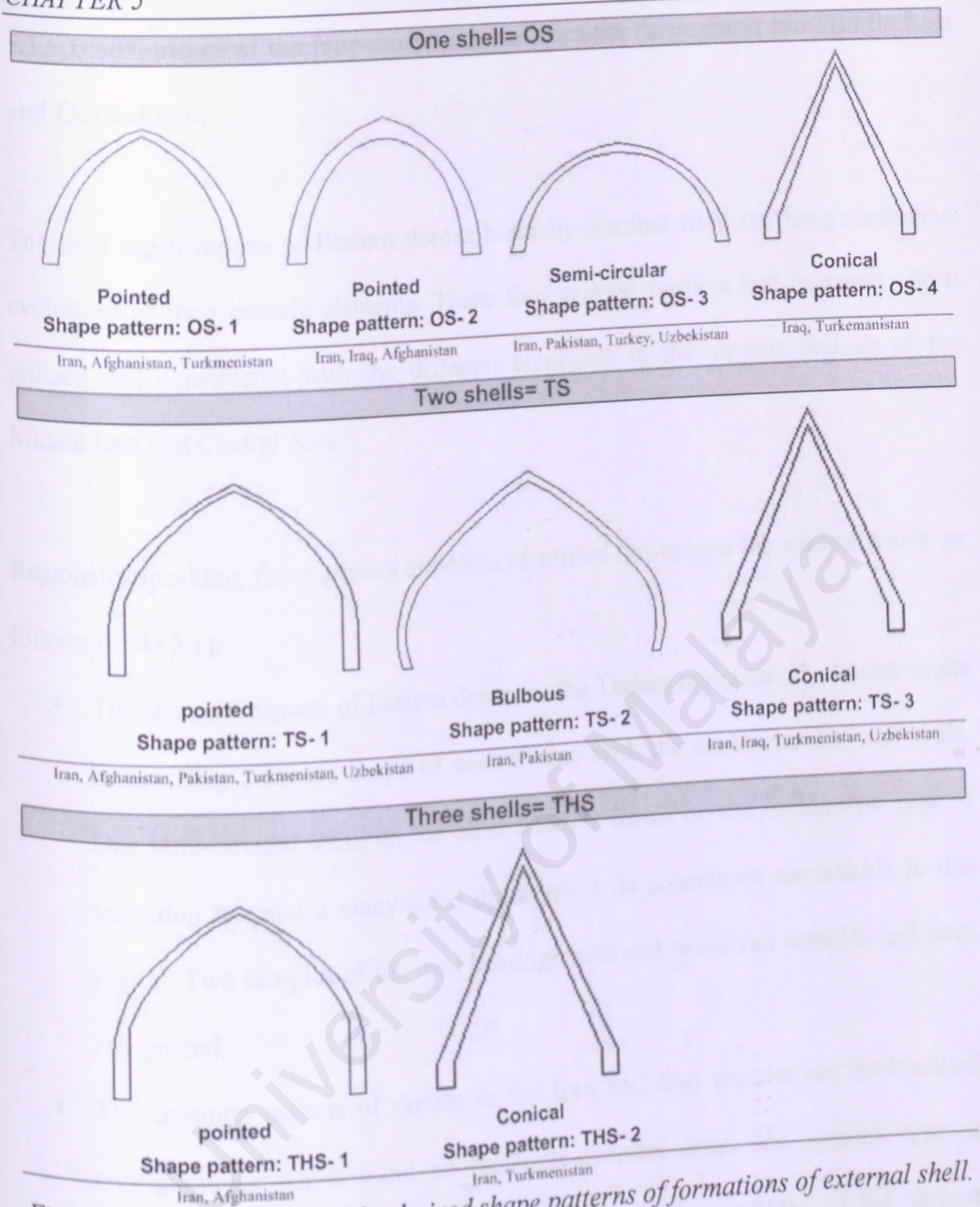


Figure 5.12: Illustrations of the derived shape patterns of formations of external shell.

5.3.5 Distributions of the four morphological features throughout the Middle East and Central Asia

The final organizations of Eastern domes basically resulted from the long continuous evolutions of their generic elements. These four general features had frequently been utilized and constructed with the different emphases in the various regions of the Middle East and Central Asia.

Regionally speaking, these aspects are often identified throughout the studied zones as follows (table 5.1):

- The common aspects of Eastern domes in the Turkey region are the lateral vaults surrounding a square shape of central plan with the enormous size and scale. One semi-circular shell, on the other hand, is rested on the *pendentives* type of transition tier and a many-sided drum which is considered remarkable in this region. Two samples of the load bearing walls and *squinches* samples had been recognized;
- The common aspects of domes in the Iran and Iraq regions are double-shell configurations which stand on the high cylinder drum and *squinch* type of transition tier. The samples of load bearing mostly consisted of the various compositions of the arches and solid walls. The frequency of one and three shells are less than the double-shell domes; some examples of the other settings of load bearing system had also been recognized such as octagonal shapes;
- The common aspects of domes in the Afghanistan and Pakistan regions are also compositions of load bearing walls with vaults and *squinches* type of transition tiers which are topped with either one or two shells domes. Nevertheless, a sample of the three shells domes had also been known. The high cylinder shape

of drum is the common aspect of this component in both regions. Note that the other forms of setting of the load bearing system had also been discovered such as octagonal shapes; and finally

- The common features of domes in the Uzbekistan and Turkmenistan regions are also bearing walls with the developed compositions of the *squinches* and a high cylinder drum which is almost always topped with two shells more than one shell domes.

Table 5.1: Common morphological and typological appearances of domes in the Middle East and Central Asia.

Common morphological and typological features of Islamic domes in the Middle East and Central Asia	
Zone I: Turkey region	**Zone II: Iran & Iraq regions**
Vocabularies Shell shape: Semi- circular Drum: not very high with many-sided shape Transition tier: *Pendentives* Load bearing system: huge lateral vaults **Grammar** Simple with drum which neither presented complexity in design nor do arrangements, except for huge size and scale	**Vocabularies** Shell shapes: Pointed, conical, and bulbous Drum: very high with cylinder shape Transition tier: *Squinches* Load bearing system: square and octagonal Load bearing systems **Grammar** Dominant compositions of domes is compound with drum and complexity in designs and arrangements.
Zone III: Afghanistan & Pakistan regions	**Zone IV: Uzbekistan & Turkmenistan regions**
Vocabularies Shell shape: Semi- circular, pointed, and bulbous Drum: very high with cylinder shape Transition tier: *Squinches* Load bearing system: huge square or octagonal types of load bearing systems **Grammars** In the Pakistan region: majority of domes are simple with and without drum. In the Afghanistan region: majority of domes are compound with drum	**Vocabularies** Shell shape: pointed and bulbous Drum: very high with huge cylinder shape Transition tier: *Squinches* Load bearing system: huge square load bearing system **Grammars** Compound with drum and complexity in their organizations, scales, geometrical designs

Table 5.2 exposes the distributions of the morphological and typological aspects [4] of the Islamic domes from the early Islamic era through into the late Islamic era in the Middle

[4] Refer to Appendix one, initial derived data for more information.

East and Central Asia. In general, during the various Islamic periods, supporting system with load bearing walls and arches are the prominent aspects of domes (70.4%) in the Middle East and Central Asia. The main features of transition tier are the various types of *squinches*.

The main configuration of domes is the double-shell (54.3%) with the cylinder drum (72. 2%) during distinct Islamic eras. Nevertheless, the distribution of one shell samples is also magnificent (40.3%) in this region compared to the three shells. The majority of domes have compound typology (56.8%) in comparison to the lower number of simple typology (43.2%).

Table 5. 2: The distributions of the morphological and typological aspects of the Islamic domes since the early Islamic era until the late Islamic era in the Middle East and Central Asia.

			Early Islamic - Early medieval Islamic eras	Late medieval Islamic era	Late medieval Islamic era- Late Islamic era		
			10^{th} -12^{th}	13^{th} -14^{th}	15^{th} -18^{th}	Total	
Morphological Features	Load bearing system	Cylinder	---	---	---	0	
		Bearing walls	9	10	19	38	70.4%
		Lateral vaults	2	---	8	10	18.5%
		Other	1	3	2	6	11.1%
						54	
	Transition tier	*Pendentives*	2	1	8	11	20.3%
		Squinches	11	11	21	43	79. 6%
						54	
	Drum	Circular	5	8	20	33	70.3%
		Many-sided	3	3	8	14	29.7%
						47	
	Shell	One shell	7	6	10	23	40.3%
		Two shells	8	5	18	31	54.3%
		Three shells	--	--	3	3	5.26%
						57	
Typological features	Dome typology	Simple	7	5	10	22	43.2%
		Compound	3	4	22	29	56.8%
						51	

5.4 General Typological Features of the Eastern Domes in the Middle East and Central Asia

The typological characteristics of the Islamic domes in the Middle East and Central Asia have been defined and addressed based on their shell configurations and emergence of the drum[5]. The common derived aspects of dome typologies can regionally be specified as follows (*see* table 5.1 and 5.2): Turkey: majority of domes have been identified simple and with drum in comparison to the compound with drum;

[5] Refer to sub-chapter 3.2.2 on typological survey of Eastern domes for more information.

- Afghanistan, Pakistan, Iran, and Iraq: majority of domes have been recognized compound with drum compared to the simple with drum. Some samples, however, did not derive any sign of drum. The simple typology without drum has been identified in the Iran and Iraq regions more than the Afghanistan and Pakistan regions; and
- Uzbekistan and Turkmenistan: the compound typology is considerably found more than in the other studied regions. The frequencies of simple typology whether with drum or without drum are utterly less than the compound typology.

It is interesting to highlight that a few samples of the compound typology without drum have been seen in the whole studied zones. However, in the dome consideration, the role of cultural effects and regional agreements cannot be overlooked.

Except for the Turkey region, the compound typology and the double-shell domes are remarkable in most of the studied countries including Iran, Iraq, Uzbekistan, Turkmenistan, Pakistan, and Afghanistan. The simple typology without and with drum are also identified in the all eight regions. However, the simple typology without drum was not recognized in the Turkey region.

On the other hand, the Turkey region includes the majority of the simple domes (64%), more than the other regions. The distributions of both compound and simple are equal (50%) in the Iran and Iraq regions; whereas the compound typology form the majority of domes (62%) in the Afghanistan and Pakistan regions. The Uzbekistan and Turkmenistan regions include the highest distributions of compound typology (82%) compared to other regions.

5.5 Common Features of the Pointed Discontinuous Double-shell Domes in the Middle East and Central Asia

The pointed discontinuous double-shell domes have so far played a significant role in the development of dome architecture as well as these include the majority of the Islamic domes from the early Islamic era through to the late Islamic period in the Middle East and Central Asia.

They conceptually appeared in certain shell configurations and geometrical structuralism that may exhibit the specific development of this sort of discontinuous double-shell domes the other dome types such as conical and bulbous domes.

5.5.1 Common Morphological Features

In general, the pointed discontinuous double-shell domes expose logical designs, with vigorous articulation of clear proportionality of their distinct elements. As a result of the analysis of the case studies, the common components (or vocabularies) of this type of the Islamic double-shell domes are morphologically listed as follows:

□ *Load bearing system*: main body of studied examples embraced the typical features of the Islamic domes, that is, the compositions of solid walls with whether blind arches or vaults which are set as positive and negative compositions, symmetrically. Figure 5.13 depicts the various shape patterns derived from the study of twelve case studies that can be addressed as follows:

-Cases 1 and 11: PP 1-10 (NP 2-8);

- Cases 2, 3, 5, 8, 9 and 10: PP 1(NP 2);

- Case 4: PP 1-6 (NP 2-5);

- Case 6 and 12: PP 1-7 (NP 2-12)

-Case 7: PP 1-8 (NP 2-10; NP 2-11)

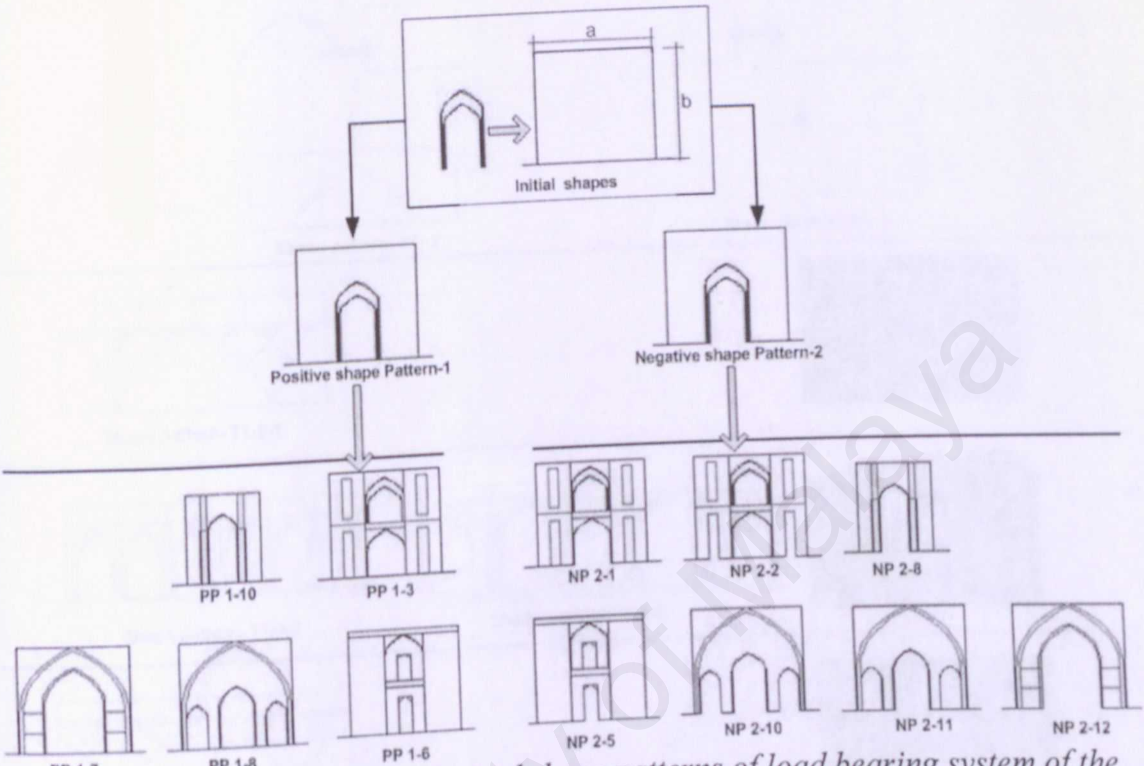


Figure 5.13 : Illustrations of the derived shape patterns of load bearing system of the pointed discontinuous double-shell domes.

□ *Transition tier*: this component showed a high level of development in the pointed discontinuous double-shell domes. Figure 5.14 presents the common compositions of the transition tiers derived from the study of the twelve case studies. Both net-vaulting *squinch* (TT 3) and the console mini-arches (TT 2) *squinch* types have been identified as the common prototype of this component in the pointed discontinuous double-shell domes. The common shape patterns of transition tier of the studied examples can be classified as follows:

-Case 1: TT 3-2;

-Case 2: TT 3-3;

-Case 3: TT 2-3

-Cases 4, 5, 7, 10: TT 3-3;

-Case 8: TT 2-1; and

-Cases 9, 11, 12: TT 2-5.

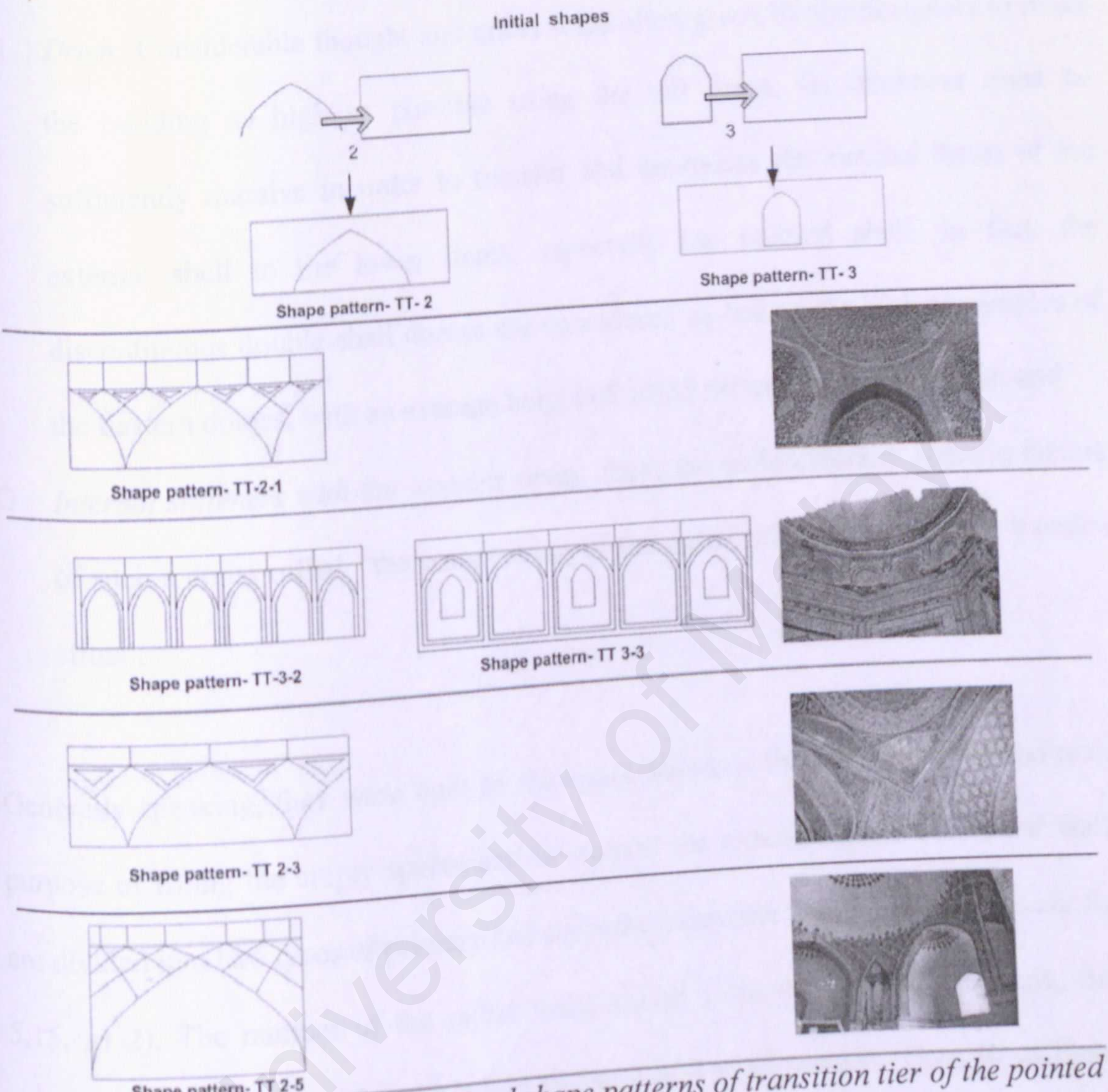


Figure 5.14: Illustrations of the derived shape patterns of transition tier of the pointed discontinuous double-shell domes.

□ *External shell:* this is what appears from the outside of the dome buildings. It is the only architectural item which was conceptually found synonymously during the several Islamic epochs. Its thickness is proportionally reduced from this base to the tip of dome at either 25' or 30' angles and it has the pointed shape pattern (see fig 5. 12 TS-1);

□ *Internal shell:* this covered the internal dome chamber and has a simple geometric formation in comparison to the external shell. In fact, it is necessary that its geometric shape fully conformed with the external shell for the purposes of transferring forces of the upper components to the lower elements;

- *Drum:* Considerable thought and effort were often given by the designers to make the building as high as possible using the tall drum. Its thickness must be sufficiently massive in order to transfer and neutralize the vertical thrust of the external shell to the lower items, especially the internal shell. In fact, the discontinuous double-shell domes are considered as one of the highest samples of the Eastern domes, with an average height of 30-35 meters from the ground; and
- *Internal stiffeners with the wooden struts:* these are architecturally specific factors of such a dome called, 'the composition of the radial brick walls with the wooden struts'.

Generally speaking, they were built in the space between the two shells for the main purpose of filling the empty spaces and to support the external shell. The radial walls are divided into two types of primary and secondary (smaller than primary ones, *see* fig. 5.15, a1-2). The number of the radial walls varied from 4 (Sultan Bakht Aqa, first sample), 6, 8, 14, to 18 within the height variance of 8 to 15 meters). They are affiliated with the size of the span. The wall thickness also changed, but not less than 40 cm has been seen (fig. 5.15, c-3).

It is necessary to point out that the arrangements of the internal stiffeners and their numbers have often been altered (fig. 5.15, c1-2) as a result of conservational interventions, such as replacement of the wooden struts with steel meshes or even removal of the wooden beams (fig. 5. 15, b-1). Another example is one of domes of the Mir Arab *madrasa* with the specific arched connections which were used to provide more stability for the whole system because of its oblique internal roof (fig. 5. 15, k-1).

They are arranged compositionally based on the vernacular architecture agreements. For example, the vertical wooden posts were often seen in the Iranian samples (fig. 5.18, d1, 2). However, the pairs of the small wooden pieces, which connected the radial walls to the drum's body, are the predominant features in Uzbekistan, Turkmenistan, and Afghanistan (fig. 5.18, e1, 2). Sometimes, the specific design had been used in the important buildings such as Gur-i Amir in Uzbekistan which has a unique composition of wooden struts inserted on a vertical brick cylinder wall.

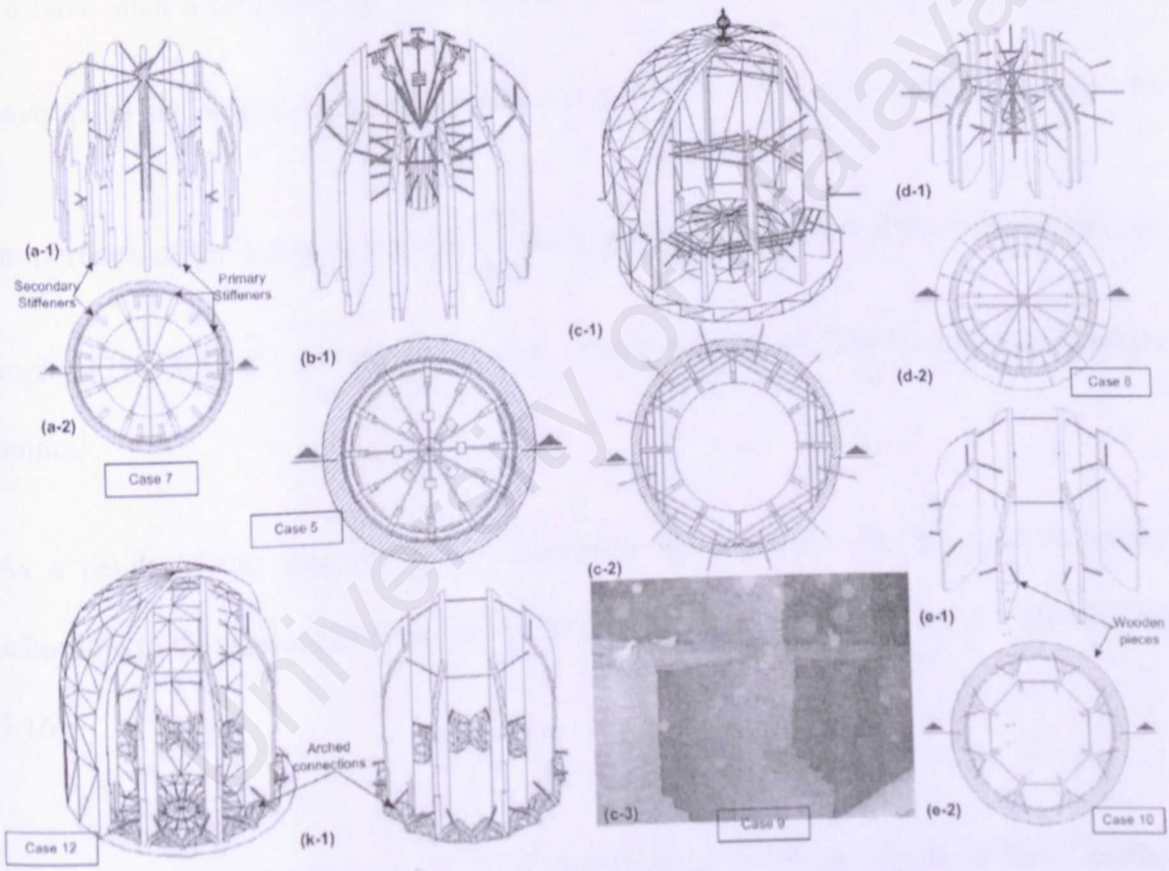


Figure 5. 15: Various internal configurations of stiffeners and wooden struts of the pointed discontinuous double-shell domes.

These wooden beams probably appeared as the long pieces embedded with the meridian stiffeners horizontally and vertically. The removable wooden struts have basically set into the devised holes located on the thickness of the brick walls (stiffeners). These wooden struts often increasingly influenced the stability of such domes in order to diffuse better the various loads for the prevention of the split by cracks.

5.5.2 Common typological and geometrical compositions

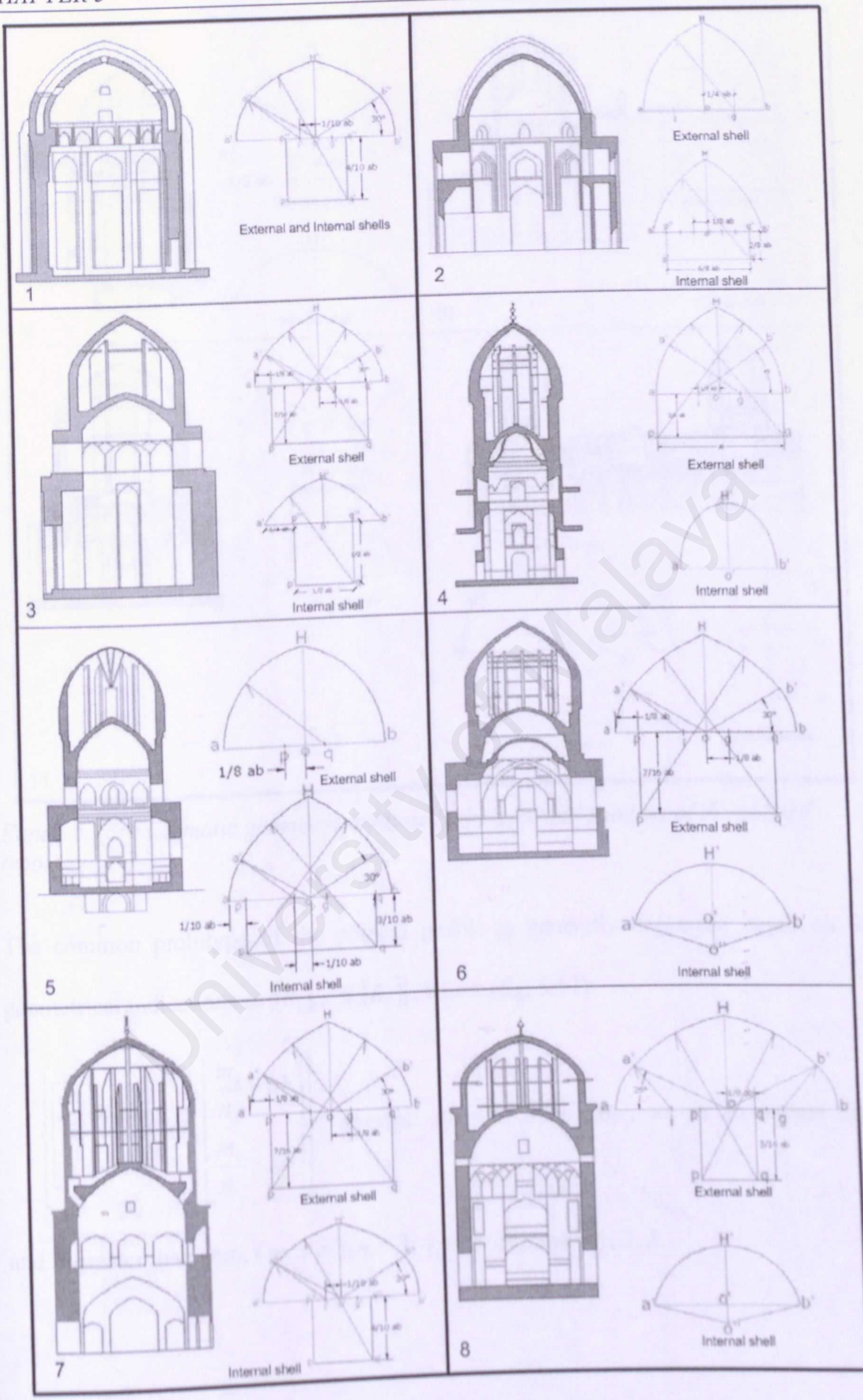
Historically, the pointed typology contained the majority of the discontinuous double-shell domes in the Middle East and Central Asia. Using the primary definition of the pointed-pattern, the generated profiles of samples are categorized in this typology, provided that their lower arcs (primary and secondary) are tangent to the two vertical lines.

To have such a property, the centre points of the lower arcs (primary and secondary) have to be set on the span line, meaning that $gg' = ii' = \frac{m_1}{n_1}$ s=0. In addition, since the proportions of the breaking points ($\frac{m_3}{n_3}$ s) on the span line do not show clear values, the angles (25', 30', 45' and 60') have thus been proposed for determining the breaking points.

As a result of the analysis of the examples, three subsets of the pointed profiles according to the number of their centre points have been recognized and configured (fig. 5.16):

- Two-centered profile: The case 2, 5 and 9 were analyzed based on the al-Kashi method and organized using the parameters of the new system: $\left\{\begin{bmatrix}2/4ab \\ 0\end{bmatrix},0,0\right\}$, $\left\{\begin{bmatrix}2/8ab \\ 0\end{bmatrix},0,0\right\}$.
- Three-centered profile: It is only identified in the case 12 according to the following geometrical parameters: $\left\{\begin{bmatrix}0 \\ 0\end{bmatrix},\angle 30,\begin{bmatrix}2/4ab \\ 1/3ab\end{bmatrix}\right\}$.
- Four-centered profiles: The majority of the cases 1, 3, 4, 6, 7, 8, 10 and 11 are categorized in this group based on the different geometrical parameters:

Case 1: $\left\{\begin{bmatrix} 2/10ab \\ 0 \end{bmatrix}, \angle 30, \begin{bmatrix} 4/10ab \\ 4/10ab \end{bmatrix}\right\}$; Cases 8 and 11: $\left\{\begin{bmatrix} 4/8ab \\ 0 \end{bmatrix}, \angle 25, \begin{bmatrix} 2/8ab \\ 5/16ab \end{bmatrix}\right\}$; cases 1, 3, 6, 7, and 10: $\left\{\begin{bmatrix} 2/8ab \\ 0 \end{bmatrix}, \angle 30, \begin{bmatrix} 6/8ab \\ 7/16ab \end{bmatrix}\right\}$; Case 4: $\left\{\begin{bmatrix} 2/6ab \\ 0 \end{bmatrix}, \angle 45, \begin{bmatrix} ab \\ 2/6ab \end{bmatrix}\right\}$.


1
External and Internal shells
2
External shell
Internal shell
3
External shell
Internal shell
4
External shell
Internal shell
5
1/8 ab
External shell
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8
External shell
Internal shell

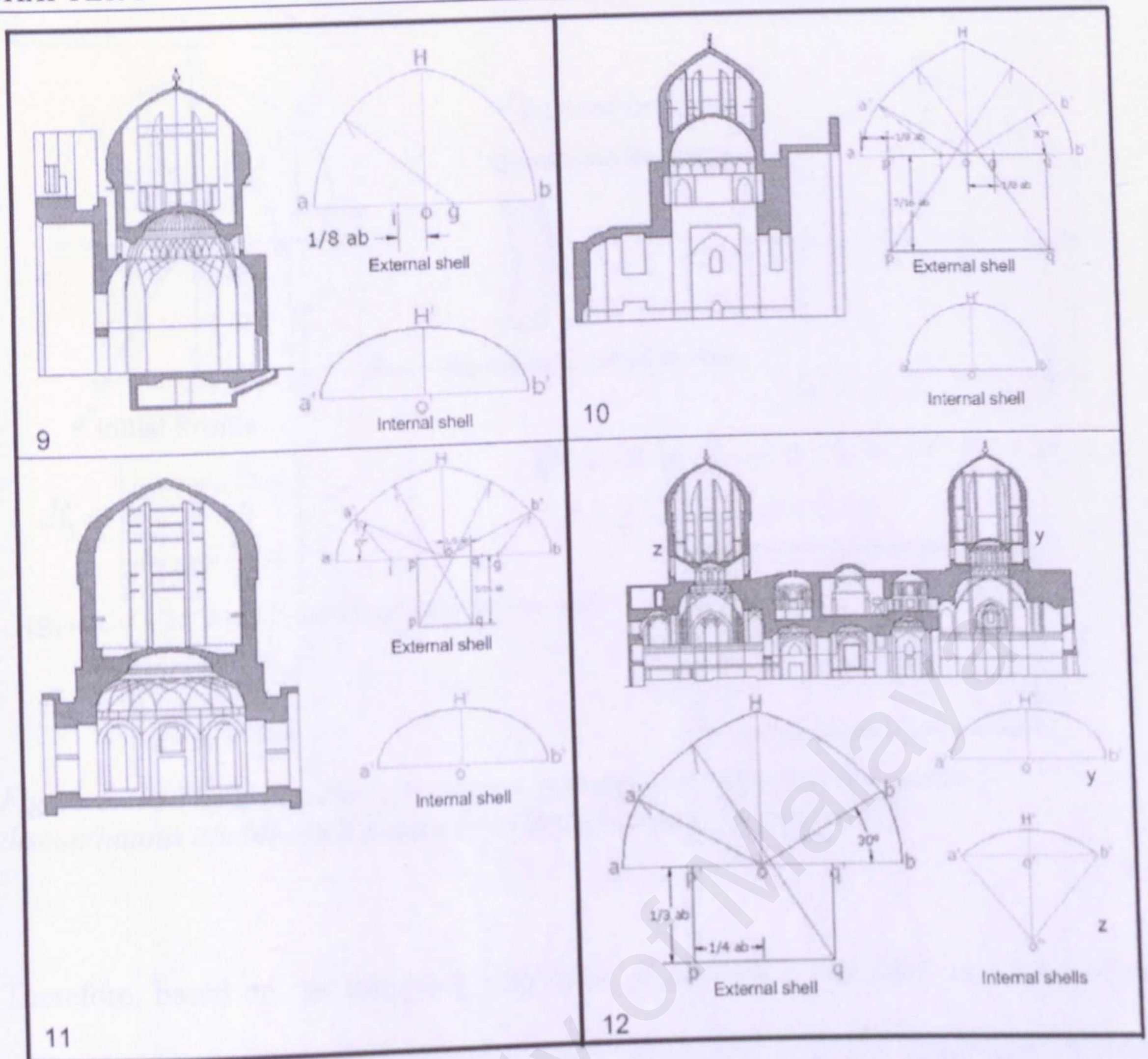
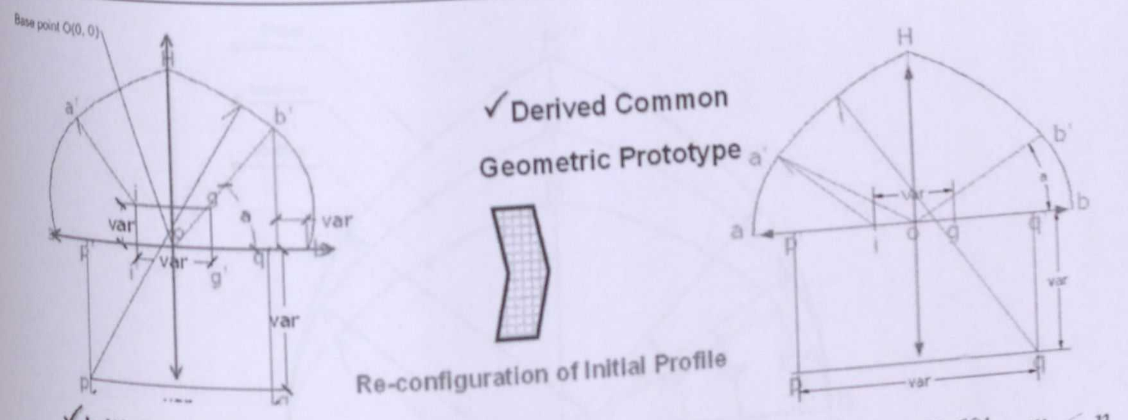


Figure 5.16: Systematic geometric analysis of the surveyed samples of the pointed typology.

The common prototype of the pointed profile is generally organized based on the geometrical indications as $\{[R_1],\angle B,[R_2]\}$, where (fig. 5.17):

$$\left\{\begin{bmatrix}\dfrac{m_1}{n_1}\times ab\\ 0\end{bmatrix},\angle B,\begin{bmatrix}\dfrac{m_2}{n_2}\times ab\\ \dfrac{m_3}{n_3}\times ab\end{bmatrix}\right\}$$, ab=span, $\angle B = 25', 30', 45', 60'$, m_i is an integer digit

and is greater than zero, ($m_i \leq n_i$), n_i = 3, 4, 6, 8, 16, and i=1, 2, 3.



Initial Profile

$$R_1 = \begin{bmatrix} ig = i'g' = \frac{m_1}{n_1} ab \\ ii' = gg' = \frac{m_2}{n_2} ab \end{bmatrix}$$

(B) = $\angle O = 25', 30', 60', and\ 45'$ or $(aa'' = bb'' = m_3 / n_3 ab, 0)$

$$R_2 = \begin{bmatrix} p'q' = pq = \frac{m_4}{n_4} ab \\ qq' = pp' = \frac{m_5}{n_5} ab \end{bmatrix}$$

$$\{[R_1], \angle B, [R_2]\}, \angle B = 25', 30', 45', 60', \quad m_i \le n_i$$

$$n_i = 3, 4, 6, 8, 16, \text{ and } i = 1, 2, 3$$

$$\boxed{\left\{ \begin{bmatrix} \frac{m_1}{n_1} \times ab \\ 0 \end{bmatrix}, \angle B, \begin{bmatrix} \frac{m_2}{n_2} \times ab \\ \frac{m_3}{n_3} \times ab \end{bmatrix} \right\}}$$

Figure 5.17: The generation of common geometric prototype of the pointed discontinuous double-shell domes from the developed general profile.

Therefore, based on the foregoing principles of geometric variables, any kind of the pointed typology of the discontinuous double-shell domes can be organized by using these geometric indications.

On the other hand, based on the variety of the external shell rises, the pointed domes can also be ranked into three sub-types: these are shallow (*see* fig. 5.18; cases 1, 8), medium (cases 3, 5, 6, 7, 9, 10, 11 and 12), and sharp (case 2 and 4). This property fully conformed to the scale of the rectangle $pp' = qq'$ and the values of angle α.

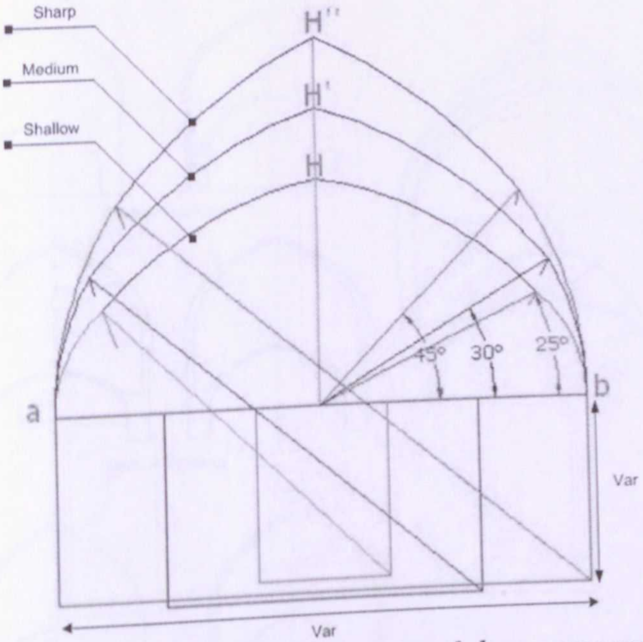


Figure 5.18: Typological classifications of the pointed domes according to the variety of their external shells' rises.

The internal shell forms are recognized as semi-circular (cases 6, 8, and 10), semi-ellipse (cases 12y, 11, and 4), pointed (cases 1, 2, 3, 5 and 7), and saucer form (case 12z). Nevertheless, the presented analysis approach with its systematical presentation not only can be utilized as the systematic elaboration of the geometric arrangements of the external shell of the pointed discontinuous double-shell domes, but it also has the potential to compose any sort of the pointed formations, such as the internal shell in a given typology such as cases 1 and 7: $\left\{\begin{bmatrix}2/10ab\\0\end{bmatrix},\angle 30,\begin{bmatrix}4/10ab\\4/10ab\end{bmatrix}\right\}$, case 2: $\left\{0,0,\begin{bmatrix}6/8ab\\2/8ab\end{bmatrix}\right\}$, case 3: $\left\{0,0,\begin{bmatrix}1/2ab\\1/2ab\end{bmatrix}\right\}$, and case 5: $\left\{\begin{bmatrix}2/10ab\\0\end{bmatrix},\angle 30,\begin{bmatrix}8/10ab\\3/10ab\end{bmatrix}\right\}$.

Based on synthesis of profiles of the external and internal shells, three common typical subdivisions can also be derived and configured including shallow, medium, and sharp templates which were composed with the different shapes of the internal shall such as saucer, semi-circular, semi-elliptical, and pointed (fig. 5.19).

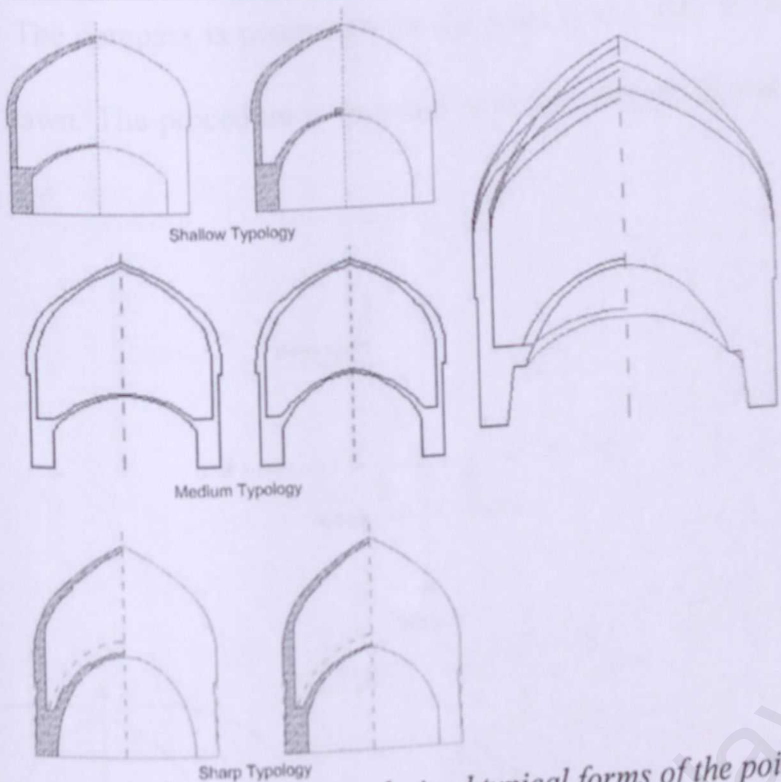


Figure 5.19: Illustrations of the common derived typical forms of the pointed domes.

In terms of elaborating on the geometric drawing steps, the four-centered profile with its geometric parameters: $\left\{\begin{bmatrix}2/8ab\\0\end{bmatrix},\angle 30,\begin{bmatrix}3/4ab\\7/16ab\end{bmatrix}\right\}$, which are considered as popular geometric attributes of the pointed typology, has been selected for detailed drawing. Note that the same method can also be adapted to draw any sort of such a profile. The construction of this sample is thus (fig. 5.20):

Step 1: The baseline ab as span is constructed and divided into 8 equal parts. The point O is set on the 1/2ab. The points i and g (named the centre points of the first and second arcs) are marked symmetrically on the 1/8 ab from the point O.

Step 2: By setting the compass on the points i and g, two circles can be drawn.

Step 3: The breaking points basically occurred at the angle of 30' from the point O for gaining points a' and b'. The centre points of the upper arcs, p and q were obtained by constructing the rectangle $pqp'q'$ under the span line, where $p'q' = pq$ =6/8ab and $pp' = qq' =$ 7/16 ab, as is shown in fig.5.20.

Step 4: The compass is positioned on the point q and with the radius qa', the final circle is drawn. The procedure is repeated with the compass placed at the point p with the radius pb'.

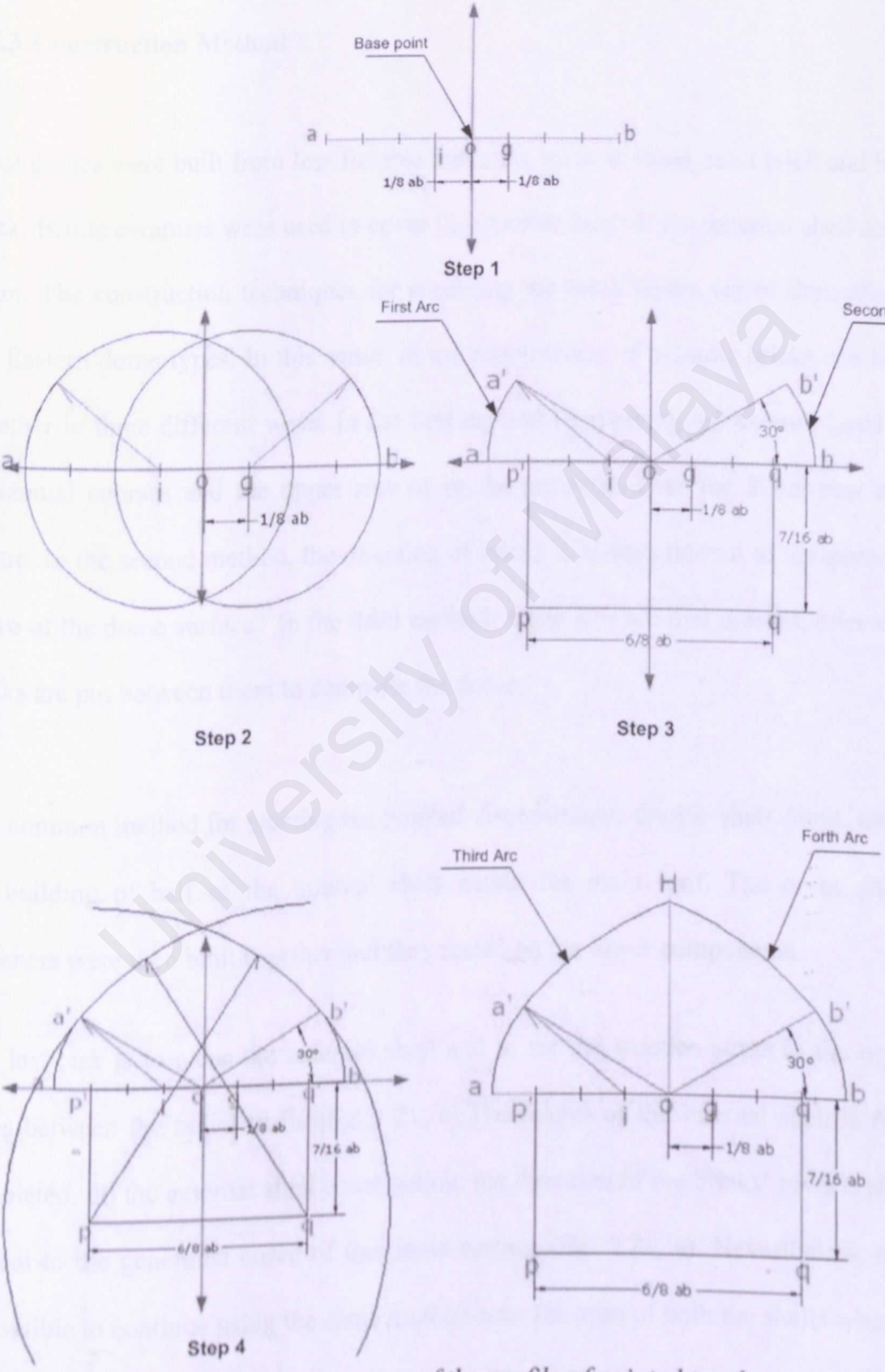


Figure 5.20. Drawing steps of the profile of pointed typology.

The exhaustive geometrical formulation of the pointed typology demonstrated its superior development and architectural conceptualism. This mainly occurred due to the collaboration of mathematicians and the architect's artisans.

5.5.3 Construction Method

Most domes were built from less flexible materials, such as stone, mud brick and baked brick. Brittle ceramics were used to cover the exterior faces of the external shell and the drum. The construction techniques for arranging the brick layers varied depending on the Eastern dome types. In this sense, in the construction of a dome, bricks can be put together in three different ways. In the first method (corbelled), bricks are placed with horizontal courses and the upper row of bricks protrudes over the lower row at the centre. In the second method, the direction of bricks is always normal to the generating curve of the dome surface. In the third method, a few ribs are first erected, after which bricks are put between them to complete the dome.

The common method for erecting the pointed discontinuous double-shell dome involves the building of half of the internal shell within the main roof. The drum and the stiffeners were then built together and they rested on the lower components.

The last task is to close the external shell and to set the wooden struts in the devised holes between the radial walls (fig.5. 21, c).The oculus of the internal shell is finally completed. In the external shell construction, the direction of the bricks' rows is always normal to the generated curve of the dome surface (fig. 5.21, a). Nevertheless, it was impossible to continue using the same method near the apse of both the shells where the empty oculuses were located. Therefore, the rows of bricks were arranged vertically (fig.5. 21, b). Finally, the metal protection was set on the kick point of the external shell in order to protect the top of the dome against rain and snow.

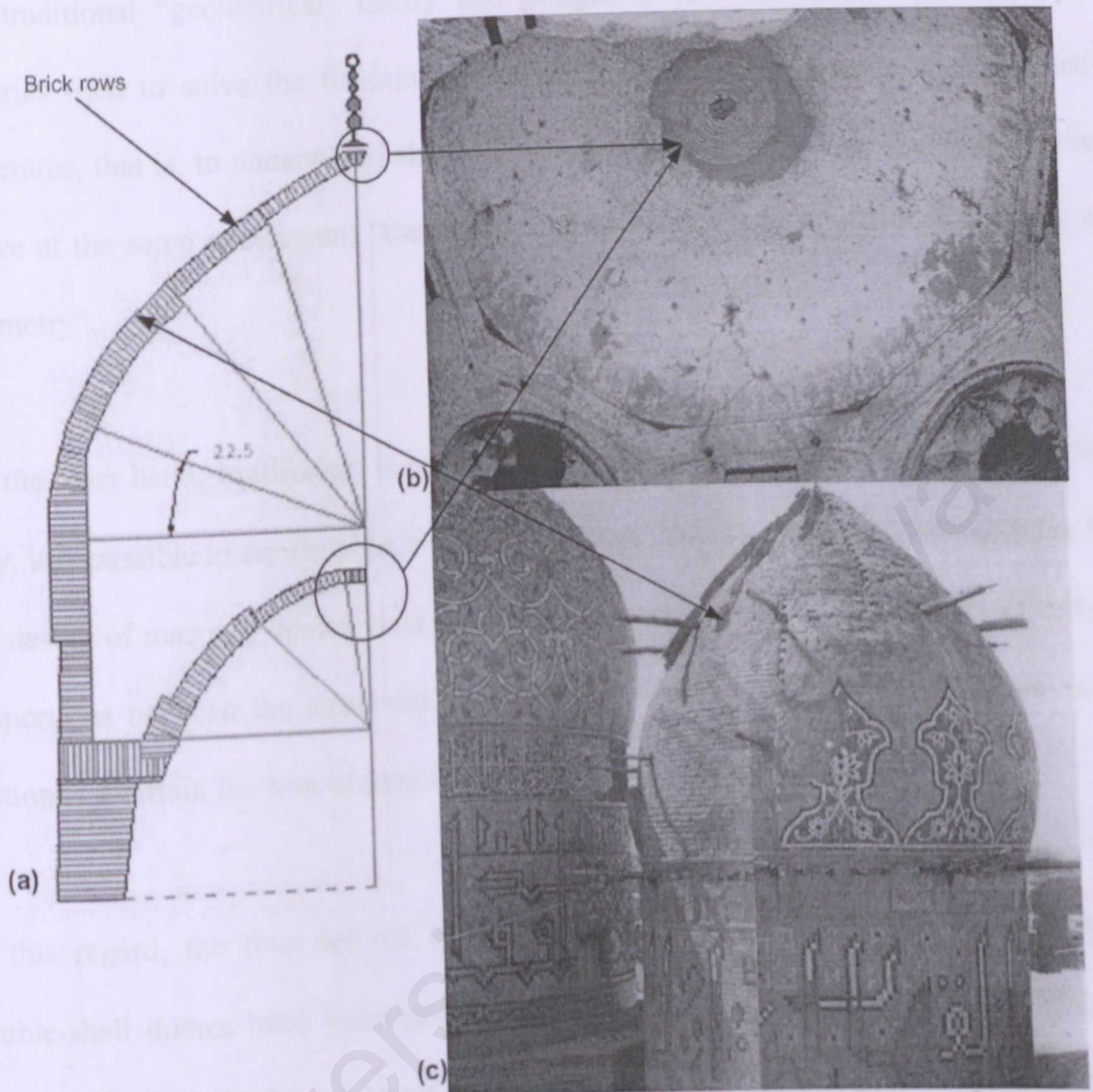


Figure 5. 21: Bricks row arrangement of the external and internal shells of the pointed discontinuous double-shell domes.

5.5.4 Structural Characteristics

The cross-section of a pointed profile essentially is a tensionless shape. The assumption of no tensile strength for masonry material leads to a geometrical criterion that requires certain minimum dimensions for all elements of the dome so that the lines of thrust are accommodated within the thickness of the dome.

Professor Heyman has incorporated this "old" theory of masonry structures within the broader frame of modern limit analysis. This scientific theory was preceded by another: the traditional "geometrical" theory and designs of the old master builders. Both theories tried to solve the fundamental problem of structural design: to design safe structures, that is, to understand what makes a structure safe (or unsafe). Both theories arrive at the same conclusion: "the safety of a masonry dome structure is a matter of geometry".

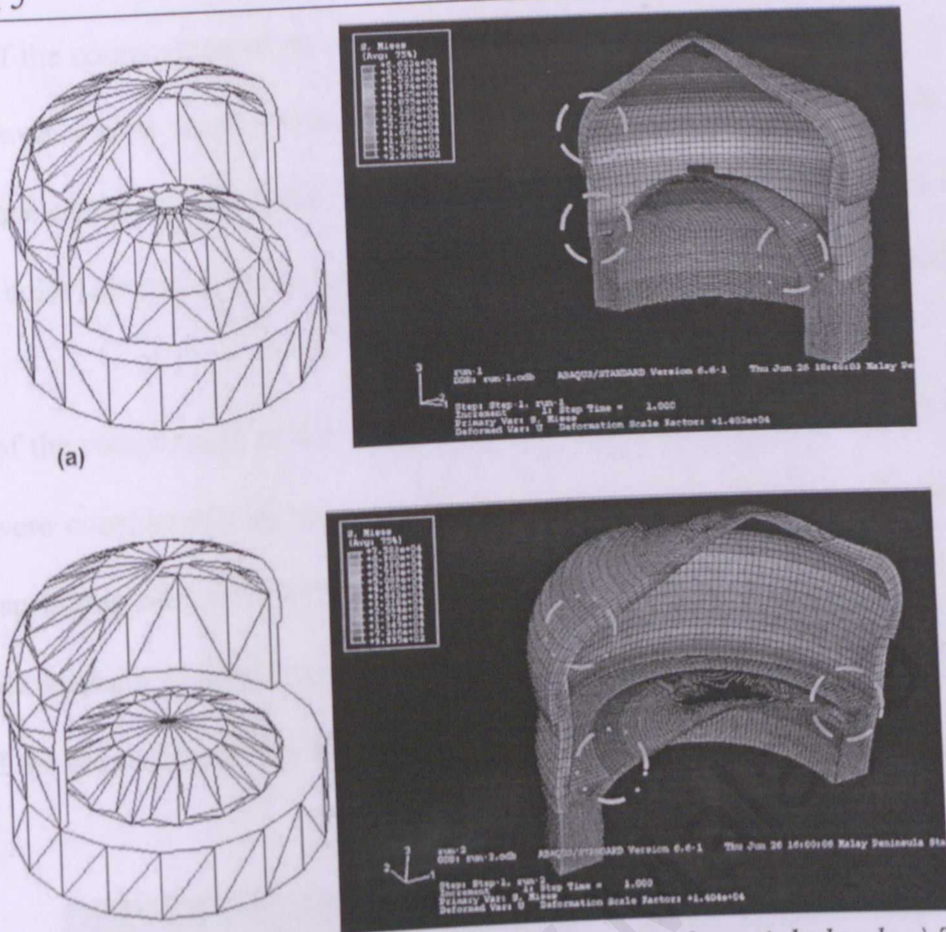
On the other hand, equilibrium is achieved through a proportional geometry and, in this way, it is possible to construct safe masonry domes. Indeed, the old traditional rules for the design of masonry domes were geometrical in such a way that they defined certain proportions between the structural elements (for example, the thickness of the wall-section is a certain fraction of span of the dome).

In this regard, the four derived typological templates of the pointed discontinuous double-shell domes have been modeled by using the ABAQUS software in order to understand generally the weakness points of such domes in their geometrical concepts. Because of close similarities existing between characteristics of the shallow and medium types, only the shallow templates have been modeled. The internal radial stiffeners are ignored so as to identify the limited shell behavior only under the gravity load.

i. FEM modeling of shallow template with the two forms of internal shell

Outer diameter of the dome template is 11m at the base. Its height from the base is 12m. The thickness of the single-shell varies from the 0.70m at the base to 0.35m at the top vertex. The shapes of the vertical cross-section of these dome templates are comprised of firstly, two intersected of the pointed and semi-circular (parabolic) formations (fig. 5.22a) and secondly the pointed and saucer formations (fig. 5.22b). The various results were obtained for both shapes of dome templates, subjected to weight load, with bending and tension suppressed throughout their shell.

In terms of composition of the pointed and semi-circular shells formations, the hoop stress (blue color) showed a high level at the external face of the internal shell. Also, considerable amount of tensile strength (red color) existed at the springing points of the external shell. A compressive tensile force with the highest level appeared at conjunctions of the drum and the internal shell (fig. 5.22a). In terms of composition of the pointed and saucer shells formations, the hoop stress (blue color) are significantly reduced; whereas tensile strength (red color) still showed considerable amount (as compressive force) at the conjunction of drum and external face of the internal shell (fig. 5.22b).



(a)

(b)

Figure 5. 22: Vulnerability of the shallow templates under the weight load; a) Template with semi-circular form of the internal shell; b) Template with saucer form of the internal shell.

ii. FEM modeling of sharp sample with two forms of internal shell

The outer diameter of the dome template is 12m at the base. Its height from the base is 15m. The thickness of the single-shell varies from the 0.97m at the base to 0.35m at the top vertex. The shapes of the vertical cross-section of this dome is comprised of firstly, two intersected of the pointed formations (fig. 5.23). The second sample consists of the pointed and semi-elliptical formations. The various results were obtained for both shapes of these dome templates, subjected to weight load, with bending and tension suppressed throughout the shell.

In terms of the composition of the two pointed shells formations, the hoop (blue color) stress showed a high level at the internal face of the external shell and also at the external face of the internal shell. A high level of the tensile strength as compressive force (red color) existed at the conjunction of the drum and internal shell (fig. 5.23a).

In terms of the composition of the two pointed and semi-elliptical formations, the hoop stresses were considerably increased at the three parts of this template: kick point of dome, at springing part of the external shell and at the external face of the internal shell. The tensile strength as compressive force had also appeared at the conjunction of the drum and the internal shell (fig. 5.23b).

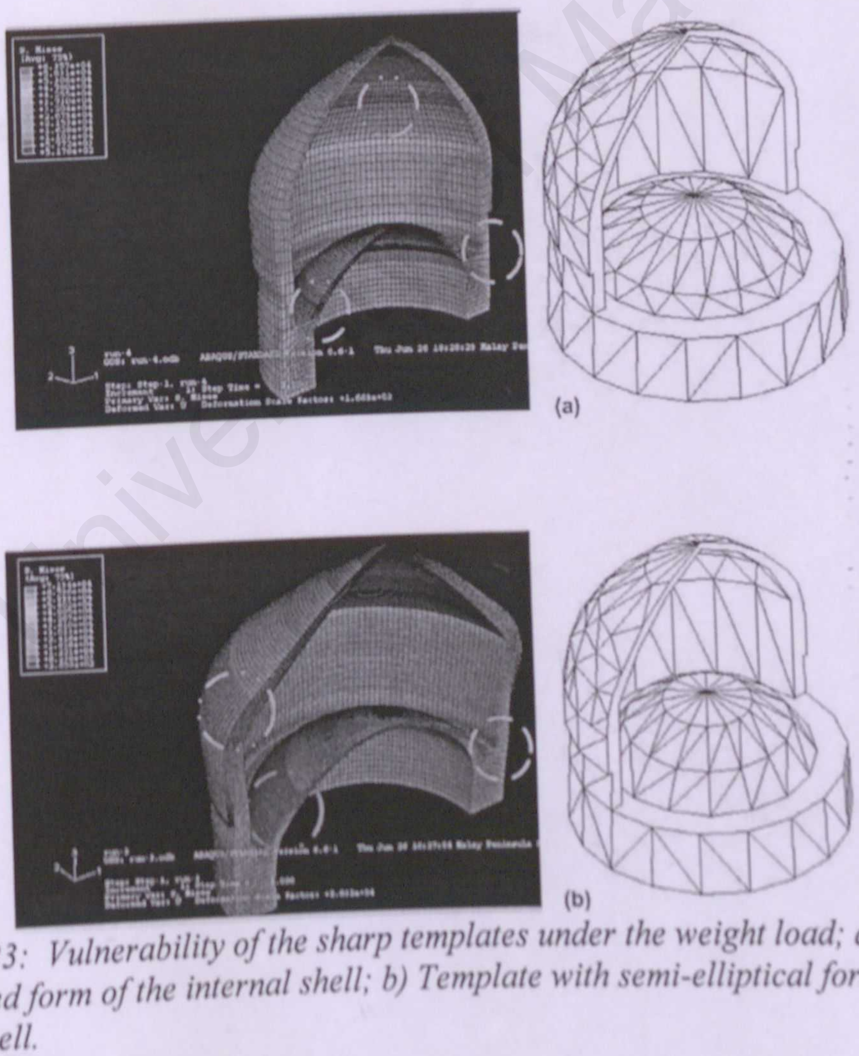


Figure 5. 23: Vulnerability of the sharp templates under the weight load; a) Template with pointed form of the internal shell; b) Template with semi-elliptical form of the internal shell.

Achieved results from structural analysis of the selected dome templates significantly proved the profound knowledge of master builders in the use of internal stiffeners and wooden struts for protecting vulnerable parts. It also demonstrated the role of geometry and certain proportions in the dome profile design which can also guarantee the stability of the masonry domes.

The analysis of four nominated samples without internal stiffeners generally represented four typical vulnerable parts (hinging points) of the pointed discontinuous double-shell domes which are clarified as follows (fig. 5.24):

1. Junction of the drum and internal shell;
2. The springing points of the internal shell ;
3. The springing points of the external shell ; and
4. Kick point of dome.

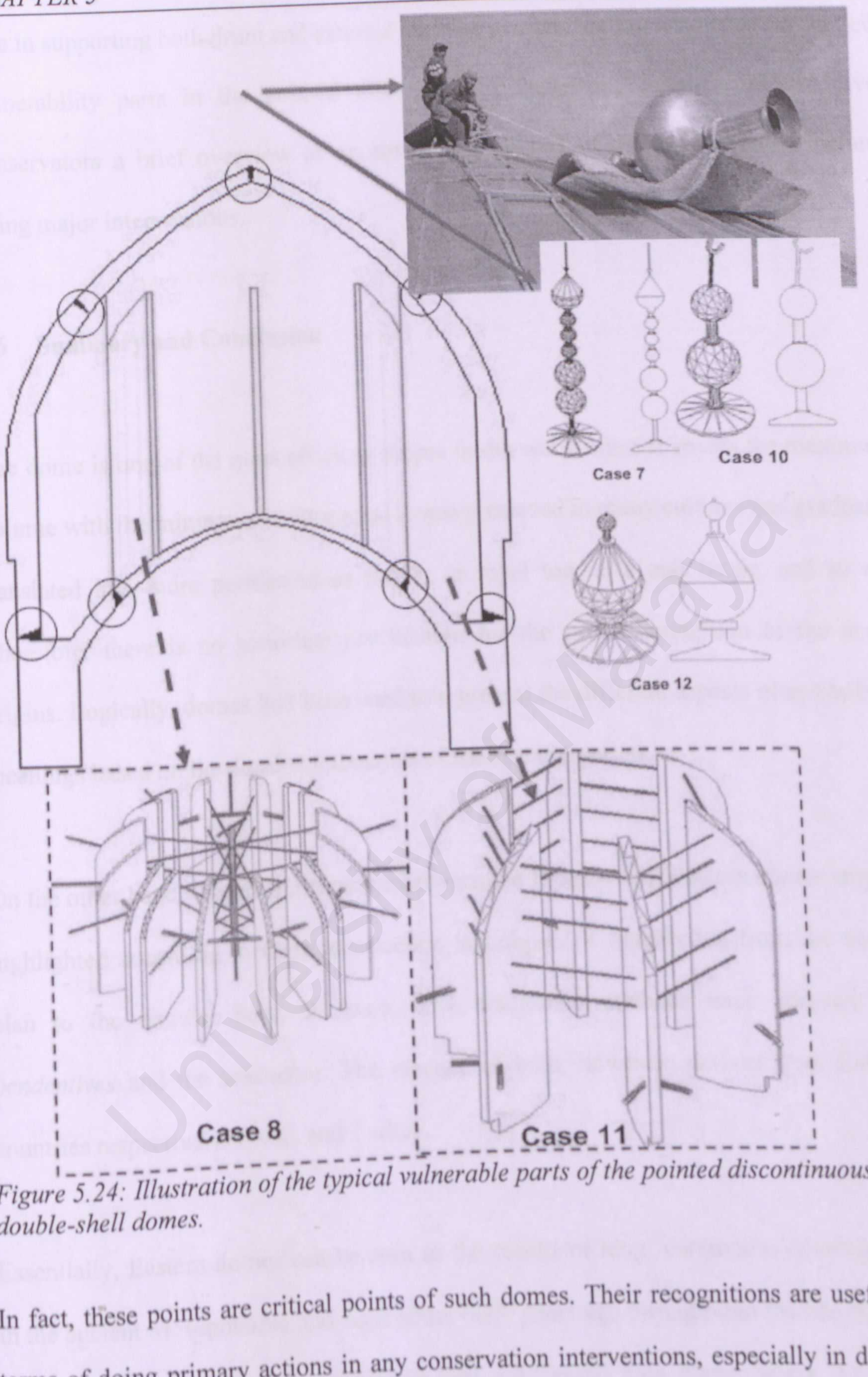


Figure 5.24: Illustration of the typical vulnerable parts of the pointed discontinuous double-shell domes.

In fact, these points are critical points of such domes. Their recognitions are useful in terms of doing primary actions in any conservation interventions, especially in danger cases. But planning and more desired interventions for improving their structural stability have to be organized based on various structural analyses and detailed considerations about causes of their damaging. Nevertheless, changing or removing the radial walls between two shells should be strongly avoided because of their buttressing role in supporting both drum and external shell. In general, the knowledge of the studied vulnerability parts in the pointed discontinuous double-shell domes help to give conservators a brief overview of approximate locations of the critical points before doing major interventions.

5.6 Summary and Conclusion

The dome is one of the most efficient shapes in the world since it covers the maximum volume with the minimum surface area. It was preserved in many cultures and gradually translated into more permanent as family or royal tombs, a cult house, and so on. Therefore, there is no historical justification for the exact assumption of the dome origins. Logically, domes had been used to represent the different aspects of symbolism meanings based on the dominant thoughts of the specific period.

On the other hand, the main difference between the Eastern and Western domes may be highlighted according to their construction techniques of transferring from the square plan to the circular base of dome. Two traditional methods were adopted: the *pendentives* and the *squinches*. The essence of both, however, derives from Eastern countries respectively: Persia and Turkey.

Essentially, Eastern domes can be seen as the results of long continuous development in the ancient Mesopotamia and Asur about 6000 years ago through into the late Islamic era about the 18th Century in the Middle East and Central Asia. Nevertheless, the dome concepts especially flourished after the coming of Islam and also with collaborations between the celebrated mathematicians who configured them based on the specific geometrical compositions. In this regard, the role of the dynasties, which developed specific architectonic structuralism in the Islamic dome cannot be overlooked.

The prominent Islamic dynasties that had ruled during various periods in these territories are respectively highlighted: Samanids (819-1005A.D.), Seljuks (1038-1194 A.D.), Ilkhanids (1256-1353 A.D.), Timurids (1370-1506 A.D.), Saffavids (1501-1732 A.D.), and Shaybanids (1503- 1800 A.D.).

The common compositional aspects of Islamic domes in each dynasty can be addressed based on their shell organization as follows:

- **Samanids**: the primary signs of collaboration of the mathematicians in the Islamic dome design as well as the construction of the semi-circular domes;
- **Seljuks**: the distinct types of the conical discontinuous double shell domes, cylinder tomb towers topped whether with the conical or pointed formations (whether one or two shells), and first appearance of the pointed discontinuous double-shell dome in the Middle East;
- **Ilkhanids:** spreading the various types the pointed discontinuous and continuous double-shell domes and continuing the construction of the conical domes;
- **Timurids:** developing the geometrical and construction properties of the pointed discontinuous double-shell domes, the dominant collaborations of the celebrated mathematicians in dome design, and appearance of the distinct triple shells domes (as a result of developing structural and architectural knowledge);
- **Saffavids:** appearing of the diverse types of the bulbous domes (named in some literature as onion shapes), continuing construction of the pointed formations, the construction of the conical domes, and ending up the evolution of the Islamic domes in the Middle East; and finally

- **Shaybanids:** continuing the construction of the pointed discontinuous double-shell domes and ending up the evolution of the Islamic domes in the Central Asia.

In fact, in the Timurid, Saffavid, and Shaybanid dynasties, the Islamic dome conceptualism reached the zenith of its development that was never surpassed in other periods. The various types of discontinuous double and triple shells are the results of these eras. Although these dynasties had directly influenced movements of the architectonic conceptualisms and configurations of the Islamic domes, the role of vernacular architectures' themes and the language of regional agreements, which specified the dome formations, cannot be overlooked.

The Eastern domes included four main components including supporting system, transition tier, drum, and shell(s) which their development during various periods manifested the final configuration of Eastern domes. As a result of the analysis on fifty three samples, the following findings can be addressed and presented:

- ***Supporting system:*** it is the main body of dome with one, two, and three opened-sides. Its architectonic concept is composition of the positive and negative arches and vaults which are set out symmetrically surrounding a central plan. Most of the domes in the Turkey region included the composition of solid walls with lateral vaults whilst the load bearing system had various compositional arrangements of the solid walls with blinded-arches and vaults in the other six regions (including Iran, Iraq, Afghanistan, Pakistan, Uzbekistan, Kazakhstan, and Turkmenistan). On the other hand, the distribution of the load bearing system as composition of the solid walls with blinded-arches (70.4%) are significantly more than the load bearing system with lateral vaults (18.8%);

- ***Transition tier:*** the common compositional aspects of transition tier are found as net-vaulting *squinch* and console mini-arches *squinch*, which are the dominant features of this component in Iran, Iraq, Afghanistan, Pakistan, Uzbekistan, and Turkmenistan regions, as well as semi-circular *pendentives* and *pendentives* with *muqarnas* rows which are only the main features of domes in the Turkey region. On the other hand, the transition tier with *squinches* formations are the dominant feature of the Islamic dome (79.6%) in the Middle East and Central Asia compared to the *pendentives* (20.3%).
- ***Drum:*** three specific formations had been recognized: many-sided, cylinder, and composition of both. The cylinder shape of drum is the dominant feature of domes in the Iran, Iraq, Afghanistan, Pakistan, Turkmenistan, and Uzbekistan regions whilst the many-sided had frequently been seen in the Turkey region. On the other hand, the drum with cylinder forms is the dominant feature of the dome buildings (70.2%) in the Middle East and Central Asia.
- ***Shell:*** The shell is the most telling of the eclectic and integrative nature of the dome building into Islamic architecture. Except for the one shell samples, the interior and exterior shells of most of the samples were often alike including double-shell and triple-shell.

From the morphological viewpoint, the most common shapes of the external shell were regionally identified in each region as follows:

-*Semi-circular*: Turkey, Iraq, Iran, and Pakistan;

-*Conical*: Iran, Iraq, Turkmenistan, and Uzbekistan;

-*Pointed*: Iran, Afghanistan, Uzbekistan, and Turkmenistan; and

-*Bulbous* (onion in some textual literatures): Iran and Pakistan.

Note that the internal shell, which is considered as the dominant feature of double-shell domes, were rarely shared similarity. Its configuration strongly affiliated with the form of external shell and also structural stability of the whole system. Nevertheless, the most common prototypes of the internal shell formations were recognized as semi-circular (saucer shape), pointed, and ribbed pointed. Nevertheless, the double-shell domes involved the majority of domes (54.3%) in the Middle East and Central Asia compared to the distributions of the one shell (40.3%) and the three shell (5.26%).

From the typological point of view, majority of Islamic domes in these studied countries had the compound typology (56.8%) in comparison to the simple typology (40.3%). The Turkmenistan and Uzbekistan regions included the majority of the compound samples (82%) compared to the other studied regions. In fact, the distributions of compound typology through the four studied zones can respectively be ranked as follows:

1. Uzbekistan and Turkmenistan regions (82%);
2. Afghanistan and Pakistan regions (62%)
3. Iran and Iraq regions (50%); and
4. Turkey region (34%).

On the whole, in dome typologies, these results were achieved basically for regional bounds, but there is also a spread of cultural types beyond the regional borders. As results of analysis on fifty three dome samples, it was demonstrated that the double-shell domes played the significant role in the dome development in the Middle East and Central Asia. The discontinuous double-shell domes included three main subdivisions such as conical, pointed and bulbous.

The pointed discontinuous double-shell domes, whose shell possess considerable distance and presented complexity in design, involve the majority of domes from the early Islamic era through the late Islamic period. As results of analysis on the twelve case studies in the four countries including Iran, Afghanistan, Uzbekistan and Kazakhstan, the six generic forms had morphologically been recognized and listed; these are load bearing system, transition tier, drum, internal shell, external shell, and internal stiffeners.

According to the developed initial profile with its new geometrical parameters, typological and geometrical languages for the pointed discontinuous double-shell domes had been specified and their associated geometrical parameters had been arranged. By using developed drawings' steps, the geometrical design for the external shell of pointed discontinuous double-shell domes were drawn and elaborated. The two typical formations, including the sharp and shallow templates and their four identified sub-divisions had been organized and configured based on the four identified internal shell shapes (including semi-circular, semi-elliptical, pointed, and saucer).

To sum up, the common method for erecting such an Eastern dome involves the building of half of the internal shell within its main roof. The drum and the stiffeners were then built together and they rested on the lower components. The last task is to close the external shell and to set the wooden struts in the devised holes between the radial walls. The oculus of the internal shell is finally completed.

Structurally, the FEM modeling of the four nominated samples demonstrated the critical role of the radial walls in stability of such domes; four vulnerable parts had also been recognized in terms of primary conservation interventions. Nevertheless, improvements of dome structural stability need more detailed structural investigations.

Chapter 6

Research Conclusion and Future Works

6.1 Research Conclusion

Eastern domes, which include the various typological and morphological conceptualisms, are widely employed to represent the different aspects of symbolic meanings, especially, after the coming of Islam. This research involved new frameworks that defined systematically their general vocabularies and grammars. In addition, the pointed discontinuous double-shell domes have been considered theoretically and practically.

Chapter Two concluded with the general proper terminologies and symbolic definitions of the Eastern dome. In general, it found out as one of the most efficient shapes in the world since it covers the maximum volume with the minimum surface area. The dome was preserved in many cultures and gradually translated into more permanent materials as family or royal tomb, a cult house, and so on. Logically, one of the oldest specific symbols of dome was the vault of heaven; that is why domes in the ancient Persia were always painted with blue or black colors.

In following, the main differences between the Eastern and Western domes were highlighted according to construction techniques of their transition tier; this element was used for transferring from the square plan to the circular base of shell(s). Two traditional methods were adopted: the *pendentives* and the *squinches*. The essences of both approaches, however, derive from the Eastern countries of Persia and Turkey. There exists a distinct and separate steps of development regarding both Western and Eastern dome architectures over historic eras. Furthermore, the influence of Islamic domes in the Western architecture cannot be disregarded.

Historically, before the coming of Islam, the oval arches and corbelled domes formed various parts of the tradition masonry building from the early beginning of the invention of the arch in the Asur and Mesopotamia. The approximately egg-shaped forms were made regularly through the use of practical geometry, perhaps about 2000 B.C., when the dimensions and the importance of their construction required.

Apart from their ancient origins, the prominent samples, which primarily appeared remains of a large dome building excavated in the Parthian capital at Nyssa (Turkmenistan) and the oldest signs of Persian Zoroastrian temples or '*chahar-taqi*' (four vaults) as innumerable samples of oval-shaped domes. Then, wooden domes were the common dome techniques in the Near East, especially in Syria and Palestine.

Soon after, introduction of using dome in Islamic architecture, every dynasty had improved technical methods and prompted new artistic qualities, without destroying the older forms. The most dominant Islamic dynasties that had ruled during various periods in the Middle East and Central Asia are respectively highlighted: the Samanids (819-1005A.D.), Seljuks (1038-1194 A.D.), Ilkhanids (1256-1353 A.D.), Timurids (1370-1506 A.D.), Safavids (1501-1732 A.D.), and Shaybanids (1503- 1800 A.D.).

On the architectural point of view, the dome can be considered as a structural consonance and a hierarchy of ordered parts, that is, the relationship between the internal space and structural mass and/or positive-negative spaces. Morphologically, the Eastern dome consists of the four general components, called vocabularies: supporting system, transition tier, drum, and shell(s). Typologically, based on how the shells are arranged together, the Eastern domes can be categorized as: one shell (the earliest type of the Eastern domes), two shells, and three shells. Triple-shell domes are considered as a developed shape of the double-shell domes in such a way that one shell almost always plays a decorative role.

Regarding the double-shell types, based on how these two shells are composed together, two subdivisions have been defined: continuous and discontinuous, respectively. In discontinuous double-shell domes, there is a considerable distance between the two shells. The discontinuous double-shell domes are specified according to their external shell shape into the three specific typologies: conical, pointed, and bulbous. The pointed typology historically contains the majority of the discontinuous double-shell domes in the Middle East and Central Asia. The exhaustive configuration of such domes showed the superior advantage of their architectural conceptualism that never observed in any other types of domes.

According to historical investigations as outlined in Chapter Two, the research was basically organized into two specific parts for answering main basic objectives of this Research:

- To exploit the general architectural language of Eastern domes including their common morphology, typologies and their distributions in the Middle East and Central Asia; and
- To identify the formal language of the pointed discontinuous double shells domes such as their morphological aspects, sub-types, geometrical design and structural characteristics.

In this regard, Chapter Three included the multifold methods which were developed according to quantitative surveys for considering the various angles of both Eastern domes and the pointed discontinuous double-shell domes, in the Middle East and Central Asia, since the early Islamic era until the late Islamic era.

In the part one of Chapter Three, the specific table (table 3.1) was quantitatively developed in order to examine, the distributions of the four morphological aspects such as supporting system, transition tier, drum, and shell(s) and two common typological aspects: compound and simple. Fifty three domes as Research samples were selected from the eight countries; these are Iran, Iraq, Afghanistan, Pakistan, Uzbekistan, Kazakhstan, and Turkmenistan.

In the second part of Chapter Three, the general geometric profile was developed, according to the *al-Kashi* approaches for the purpose of derivation process of the geometrical concepts of the pointed discontinuous double-shell domes. The biggest challenge was in creating the flexibility of the initial profile, especially in the breaking point locations that allowed the possibilities of covering various dome designs. The results included two optional characters for the breaking point reorganization. Additionally, their architectonic morphological aspects and characteristics had also been evaluated. Then, a new parametric system was proposed for formulating the geometrical characteristics of this developed general profile.

Chapter Four represented the historical and architectural explanations of case studies and their associated analyses based on the proposed methods from Chapter Three.

According to the presented results in Chapter Five, general generic features of domes in this realm can be addressed as follows: load bearing system with compositions of the solid walls and blinded arches (70.4%), *squinches* transition tier (79.4%), cylinder drum (70.2%), and two shells (54.3%). The dominant distribution of their typological appearance in the Middle East and Central Asia encompasses the compound typology (56.8%) which included respectively the majority of domes in Uzbekistan and Turkmenistan (82%), Afghanistan and Pakistan (62%), Iran and Iraq (50%), and finally Turkey (34%).

The derived morphological features are listed including five shape-patterns of load bearing system, five shape-patterns of transition tier, the external shell characteristics and its associated geometry, the internal shell properties, both shells' formulations, the drum characteristics, and composition aspects of the radial stiffeners.

Regarding the second part of Research, by using the general geometric profile with its new geometrical parameters, typological and geometrical languages of the pointed domes were put forward. Twelve case studies of such domes were selected from four countries: Iran, Afghanistan, Uzbekistan, and Kazakhstan. The morphological traits these examples, however, shared some similarities with the previous studied cases in the part one of Research.

Then, the common geometric profile of the pointed discontinuous double-shell domes was generated and their geometrical language presented based on the proposed parametric system. In this sense, three sub-types of the pointed domes are ranked based on the geometrical patterns of their external shells; these are the shallow, medium and the sharp types. Finally, a sample of geometric drawing steps was also extensively elaborated.

To sum up, despite the variation in the construction techniques for arranging brick layers of shells, the direction of the bricks' rows is always normal to the generated curve of the dome surface. In the last step, the structural analysis of four nominated samples approximately showed that there exists four typical vulnerable parts (hinging points) such as junctions of the drum and internal shell, the spring points of the external shell, the spring points of the internal shell, and subsequently, kick points of the dome. Recognizing the approximate locations of these points is necessary when planning primary actions in any conservation interventions.

6.2 Contributions to Knowledge

The Research concludes with primary and secondary findings that can contribute to the body of knowledge; the primary contributions of this Research can be listed as follows:

1. Developed specific general profile based on the *al-Kashi* geometric principles, not only for analyzing both the pointed and bulbous domes, but it also offer a unique computational classification method for design analysis of the majority of Eastern domes. In fact, it is a theoretical framework which was geometrically developed for exhibiting the essences of the geometrical compositions of both the bulbous and pointed domes;

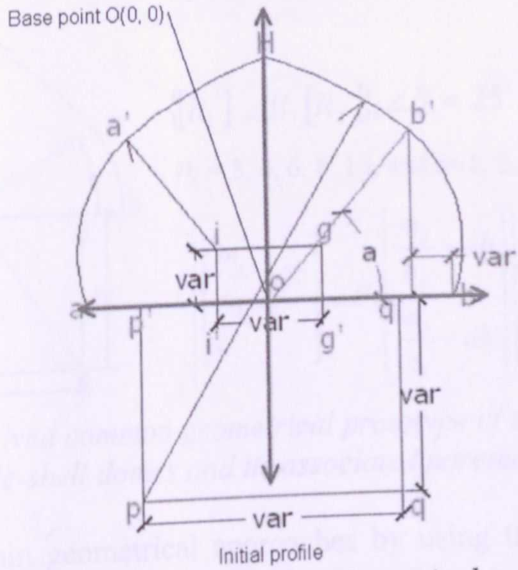


Figure 6.1: The generated initial profile for geometrical analysis of both the bulbous and pointed domes (Ashkan and Yahaya, 2009).

2. Developed newly parametric system to formulate the derived geometrical parameters of any profiles of both pointed and bulbous domes including their breaking points and locations of centre points;

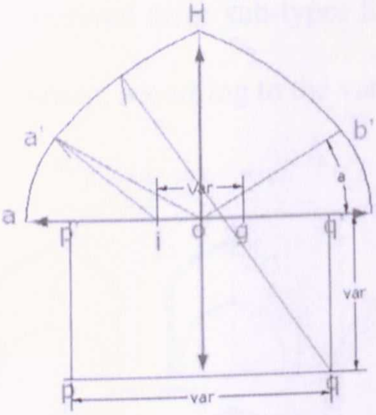
$$\{[R_1], (B), [R_2]\} = \{\text{ Rectangle 1, Breaking Points, Rectangle 2}\}$$

$$R_1 = \begin{bmatrix} ig = i'g' = \frac{m_1}{n_1} ab \\ ii' = gg' = \frac{m_2}{n_2} ab \end{bmatrix} \quad (B) = \angle O = 25', 30', 60', \text{ and } 45' \quad \textbf{or} \quad R_2 = \begin{bmatrix} p'q' = pq = \frac{m_4}{n_4} ab \\ qq' = pp' = \frac{m_5}{n_5} ab \end{bmatrix}$$

$$(aa'' = bb'' = m_3 / n_3 ab, 0)$$

Figure 6.2: The proposed parametric system to formulate geometrical indications of the generated initial profile, for both the bulbous and pointed domes.

3. Developed the common geometrical prototype for the typical pointed discontinuous double-shell domes that help not only to demonstrate their systematical arrangements and designs, but there are possibilities for generating new design criteria in the temporary design;



$$\{[R_1], \angle B, [R_2]\}, \angle B = 25', 30', 45', 60' \text{ , } m_i \le n_i$$

$n_i = 3, 4, 6, 8, 16$, and $i = 1, 2, 3$

$$\left\{ \begin{bmatrix} \frac{m_1}{n_1} \times ab \\ 0 \end{bmatrix}, \angle B, \begin{bmatrix} \frac{m_2}{n_2} \times ab \\ \frac{m_3}{n_3} \times ab \end{bmatrix} \right\}$$

Figure 6.3: The Derived common geometrical prototype of the pointed discontinuous double-shell domes and its associated parameters.

4. Developed certain geometrical approaches by using the compass to draw the profile of the pointed discontinuous double-shell domes; it is possible that this approach is employed for drawing the initial profiles of the other sorts of Eastern domes such as bulbous samples;

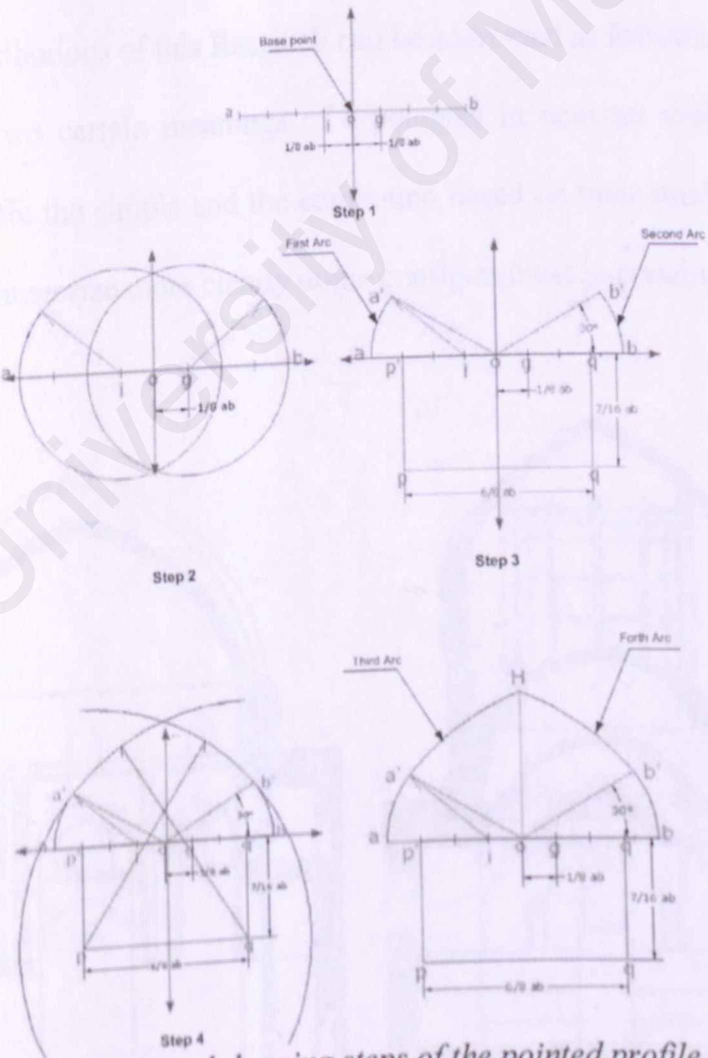


Figure 6.4: Geometrical drawing steps of the pointed profile typology.

5. Derived three sub-types for the pointed domes; there are shallow, medium, and sharp, according to the variety of their external shell rises;

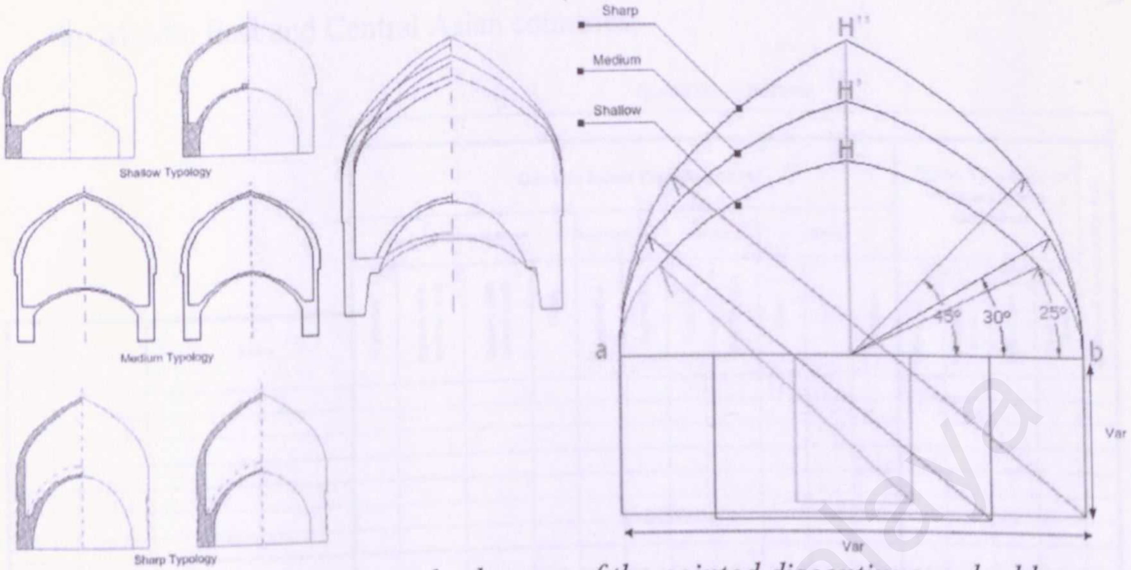


Figure 6.5: The common derived sub-types of the pointed discontinuous double-shell domes.

The secondary contributions of this Research can be addressed as follows:

6. Developed two certain meanings of typologies in contrast with the previous ones; these are the simple and the compound based on their final compositions in order to categorize more clearly dome configurations in certain groups;

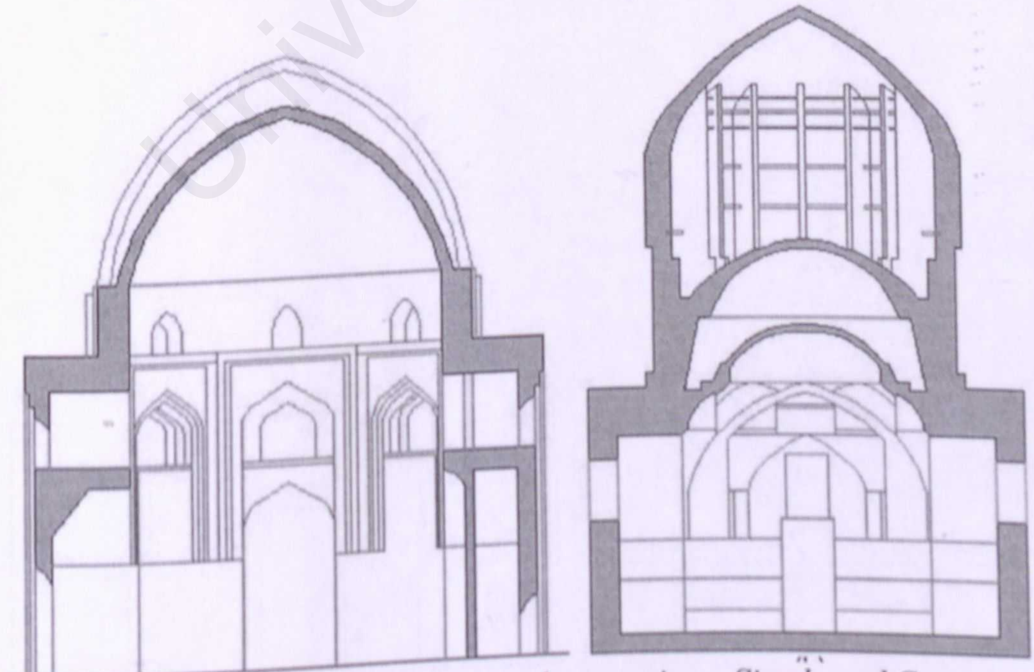


Figure 6.6: Two developed typological expressions: Simple and Compound.

7. Developed specific approach by organizing a table based on the four morphological and two typological features of the Eastern domes in order to analyze their formal language and also to estimate their distributions throughout the Middle East and Central Asian countries;

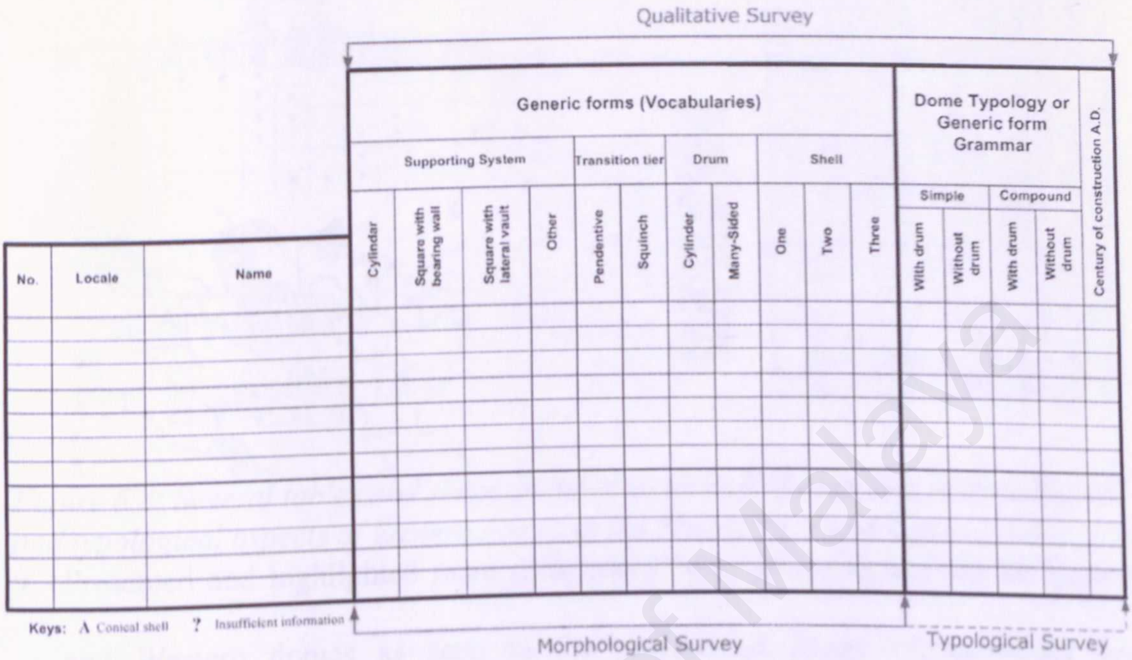


Figure 6.7: The provided table for qualitative consideration of samples.

8. Discovered and highlighted common morphological and typological aspects of domes and their emphasis in the eight regions of the Middle East and Central Asia by means of the distinct drawn shape-patterns and tables;

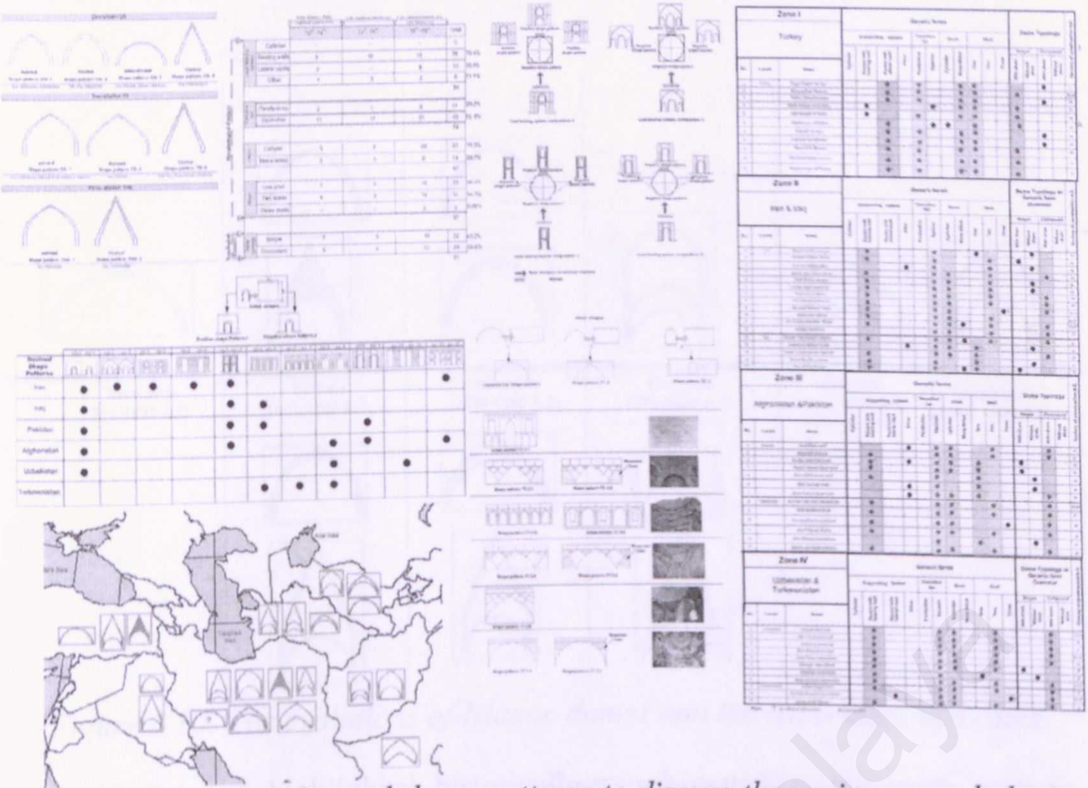


Figure 6.8: Several tables and shape-patterns to discuss the various morphological and typological aspects of Eastern domes in the Middle East and Central Asia.

9. Presented and highlighted main differences between configurations of Eastern and Western domes as seen in the preferential usage of *squinches* and *pendentives* respectively;

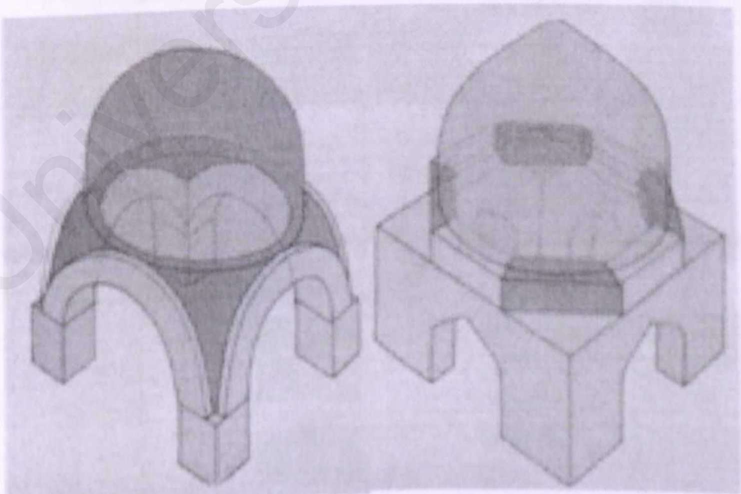


Figure 6.9: The main difference between Eastern and Western Domes.

10. Manifested relationships between the some of Islamic dynasties, which caused developments of the certain dome styles such as, Seljuks and Timurids, since the early Islamic throughout the late Islamic period in the Middle East and Central Asia;

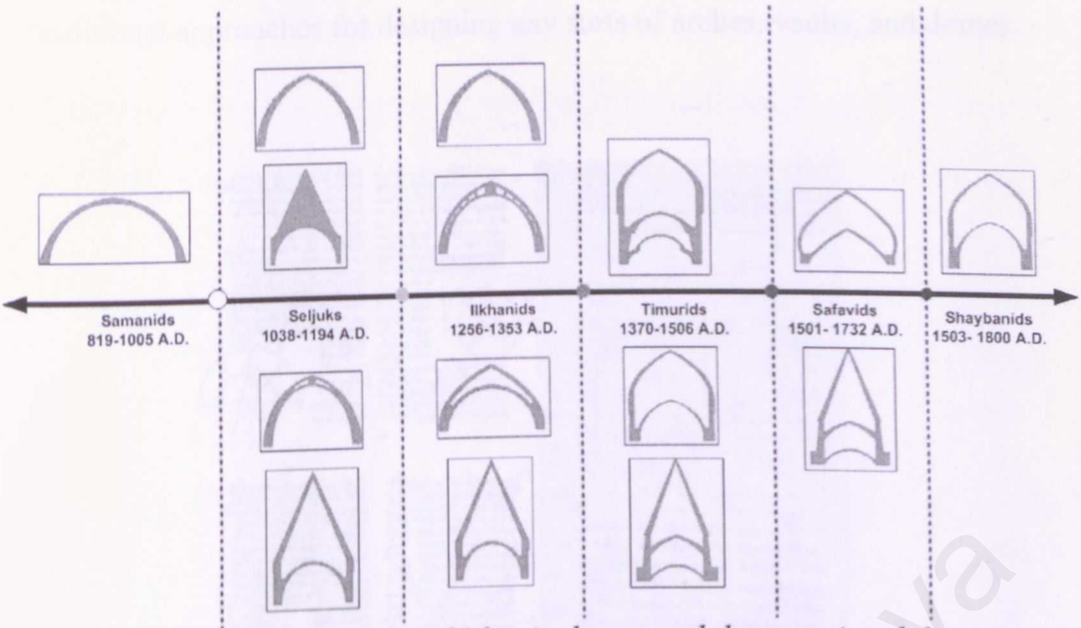


Figure 6.10: The evolutions of Islamic domes and the associated dynasties.

11. Manifested and highlighted historically-morphologically the main process in evolution of the Eastern domes over historic eras historically and morphologically by organizing the specific time line; and finally

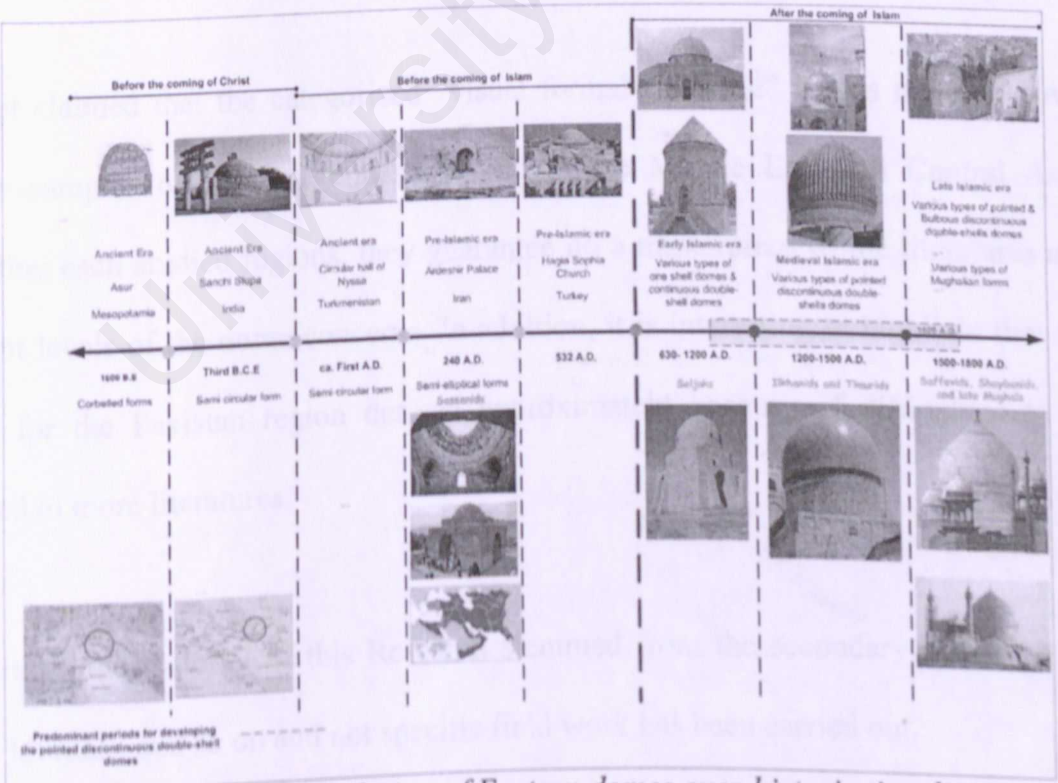


Figure 6.11: The evolution of Eastern domes over historic time line.

12. Manifested and highlighted roles of the Islamic mathematicians including *al-Khorezmi, al-Fargani, Ibn-Sina, Abu Sahl al-Quhi, Abu'l- Wafa Buzjani*, and

Ghiyath al-Din Jamshid Kashani in the Islamic dome designs and their traditional approaches for designing any sorts of arches, vaults, and domes.

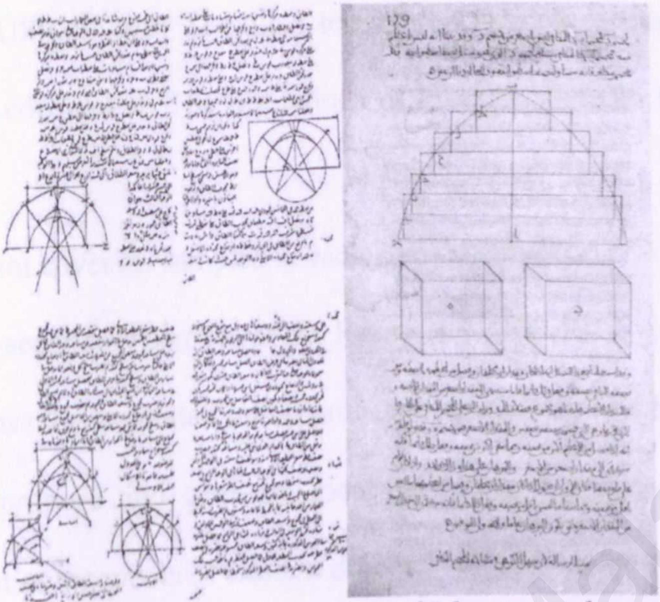


Figure 6.12: Two textual signs of collaborations of Islamic mathematicians in dome design.

6.3 Limitations and Future Works

It is not claimed that the categorized "visual formal language" in this research cover entirely samples of Eastern domes existing in the Middle East and Central Asia. Regarding each studied regions, they guarantee no a masterpiece of the literatures and different levels of the dome concerns. In addition, it is interesting to highlight that the results for the Pakistan region derived approximately because of difficulties to be accessed to more literatures.

In addition, the material of this Research stemmed from the secondary data such as, books, journals, and so on and not specific field work has been carried out.

The developed initial profile and its parametric system are able to be used for analyzing only the pointed and bulbous domes and do not cover the conical and Mongolian typologies of the Eastern domes. In terms of analysis of the Mongolian domes, it is necessary to propose additional geometrical indicators with the new parametric system. On the structural point of view, the modeled samples only analyzed under the gravity load in the ABAQUS software. The other tensile forces such earthquake, wind, snow, etc. have not been considered. The limitations of this research can briefly be listed as follows:

- To not cover all samples in each studied country;
- The secondary sources of the Research material;
- To use the generated initial profile for analyzing Mughal domes;
- To propose and generate more geometrical approaches for analyzing other components of Eastern domes;
- To structurally analyze the samples only under the gravity load in the ABAQUS software.

In fact, this research is only a starting point for engineers, architects, architectural historians to utilize the more geometrical approaches for considering architecturally-structurally the various sorts of Eastern domes in any parts of Asia. Regarding engineers, the results of this research highlighted that there are not specific structural considerations of Islamic masonry domes in the Middle East and Central Asia.

In addition, the proposed table (table 3.1) with its morphological and typological contexts has the potential to be developed for analyzing more quantitatively such as, values of those vocabularies emphasis, not only for estimating historic dome buildings in any regions of Asia, but also it can be used for main architectonic components of both historic and temporary edifices (*see* Appendix 1).

Furthermore, usage of the general profile based on the developed geometric parameters, and presented by the parametric system, has the potential for offering a unique computational classification method for the design analysis and geometric definitions of the Eastern domes, such as the Mongolian samples, one shell dome, and so forth.

Simultaneously, the results of this systematic geometric analysis could be recognized by using computational approaches including shape grammar and genetic algorithm in order to generate any kind of Islamic dome configuration and to develop a more advanced archive and retrieval system for similar data. To sum up, some significant proposals for future works can be underlined as follows:

- To develop geometrical parameters of the generated initial profile for analyzing Mughal domes;
- To propose and generate more geometrical approaches for analyzing other components of Eastern domes;
- To develop the qualitative provided table into the quantitative table;
- To use computational approaches: shape grammars and genetic algorithm to create new designs;
- To evaluate structurally more aspects of stability of Eastern domes.

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Appendices

APPENDIX A

-Translation of some pages of Al-Kashi manuscript, 'key of Arithmetic (Book IV) from Memarian (1988):

Ghiaseddin Jamshid son of Masoud-Ibn-Mahmoud-Ibn- Mohammad Tabib was a native of Kashan. Syllogistically, his date of birth is assumed to be in late 8th century about the year 790 and his death is assumed to be about 832 hegira. The history of his family shows that his family members were educated in medicine. However, he preferred to learn mathematics and astrology and he progressed in the said fields in way that he surpassed all other contemporary scientists. He continued his studies in astrology and mathematics under the tutorship of one of the students of Khajeh Nasireddin Tousi(deceased in 672 hegira) the founder of Maragheh observatory and the great Islamic scientist.

Some believe that his traveling to Samarghand was due to his acquaintance with Ghazizadeh Roumi , one of the scientists of Asia Minor and some believe the improper conditions of Kashan city and the unkindness towards scientists to be the reason. Any way, he decided to travel to Samarghand where great scientists from different cities resided. Due to his courtesy and intelligence, he surpassed other scientists of Samarghand city and became outstanding in so many scientific sessions attended by most of these scientists.

Kashani's books (Alkashi) are written in Persian and Arabic(such as Miftah al-Hisab which is written in Arabic). The handwritten copies of Meftaholketab can be found in different libraries of the world. Some of these libraries are:

- Saltikof Library of Leningrad (No. 131)
- Lion Library
- Berlin library
- Public library of Berlin

- Paris Library
- British Library in London

1. 'Miftah al-Hisab' and the scientific studies on the structures existed before 18th century

The significance of *Miftah al-Hisab* book can be evaluated in three eras. Before Ghiaseddin, contemporary to Ghiaseddin and after him. This research aims at studying the fourth article of his book on geometry and the ninth chapter of his book on "arch, vault, and dome" and we compare them with other studies conducted. *Miftah al-Hisab* includes a prologue on definition of calculus, and numbers and their types, and five articles as follow:

1. First article: on integer numbers
2. Second article: on fractions
3. Third article: on astrological calculus
4. Fourth article: on area: this article includes 9 parts. Part 9 is on the area of curve, shallow dome and *muqarnas*.
5. Article 5: extraction of the unknowns of algebra

From the five articles mentioned above, the fourth article and its ninth part deal with solving architectural problems. It was the first time that a mathematician dedicated a part of his book to an architectural subject, here, the area of buildings. This was unprecedented until mid 17th century. No one wrote a book on theories and definitions of arched structures before Ghiaseddin Kashani. In the sixth book from the ten books of Vitruvio, dedicated to architecture, he notifies that the arches transfer a kind of thrust force to its bases.

2. A theory from *Miftah al-Hisab* book, on arch, vault and dome

As it was stated above, before Mid-17th century, no book had been written in Europe to provide perfect definitions on vaulted structures. Al-Kashi first provides some definitions on arches, vaults and domes and the way they are drawn and next provides a practical method for applying them. He himself divides this chapter into three parts: area of vault, arch and dome and *muqarnas*. At the beginning of his discussion, he notifies that no one has ever studied on the area of buildings. Before starting his discussion on the drawing of different arches, he provides readers with some definitions in this regard. He believes that in the past semicircle arches were not used often and he declares that he have not seen such thins before.

The arches discussed by him mostly have a middle edge. From his point of view, an arch is divided into five parts laid on two bases on one sheet and between two parallel lines. He states the name of the five parts and mentions the difference between arch and vault. According to him, arch is a shape with a span bigger than its depth, while, a vault is just the opposite, with its depth bigger than its span. Next he initiates five methods for the drawing of arches:

In the first method, he draws a circle and divides it into 6 parts. Next he selects two centers for the arch and draws it. He believes this arch to be suitable for openings of up to 5 *Zars*. Each *Zar* equals 106.6 cm. In the second method, the main semicircle is divided into 4 parts and its tail makes two arch centers on the line crossing the arch base vertically and the other center of the arch is the semicircle center. This arch has a higher raise and is suitable for spans of 5, 10 and 15 *Zars*. In the third method, half of the arch span is divided into 4 parts and one part is assumed as the arch center. The other arch center is a point parallel to the arch base. He believes this arch to be suitable for spans larger than 10 *Zars*. The 4th type of the arches is formed by dividing the span into three parts. This arch has a high raise; however, the author has not mentioned the size of the span.

In the fifth method, the arch is drawn by making a square under its span and by selecting two vertices as the arch centers. This type of arch has a lower raise and the author has not mentioned the size of span covered by the arch.

It is noteworthy that in practice, some of these methods had been used to design arches. After providing some definitions and explaining the methods mentioned above, Kashani (al-Kashi) presents some tables. The tables include Indian and Arabic numbers. In these tables he introduces concave length methods of the arches. Actually to calculate the concave length, we can multiply the span by a number suggested by him and we have to consider that he gives us a number for each of the five drawing methods.

In the second part of the ninth chapter of fourth article, Kashani provides readers with some methods to calculate the area of domes. He mentions some types of vaults including semi-circular domes and conical domes and domes resulted from circular rotation of one of the above said arches around a vertical axis.

The area of the first and second vaults is presented in the previous chapters of the book on geometry, sphere and cone. Thus here he only discusses the area of the third type. The important point is that there is a similarity between the definition of dome provided by Kashani and the definition provided by the French researcher Pierre Bouguer in 1734. According to Kashani, dome consists of some curved lines rotating on the perimeter of a circle and Bouguer's definition is almost the same. Actually, illustrating Kashani's words in mathematical language we will see that the definitions provide by these two are the same. After discussing the dome area, he provides methods to calculated the volume of the dome (the filled part of dome). In part 3-chapter nine of the fourth article, Kashani discusses *muqarnas* and provides some details on calculating the area of various types of *muqarnas*.

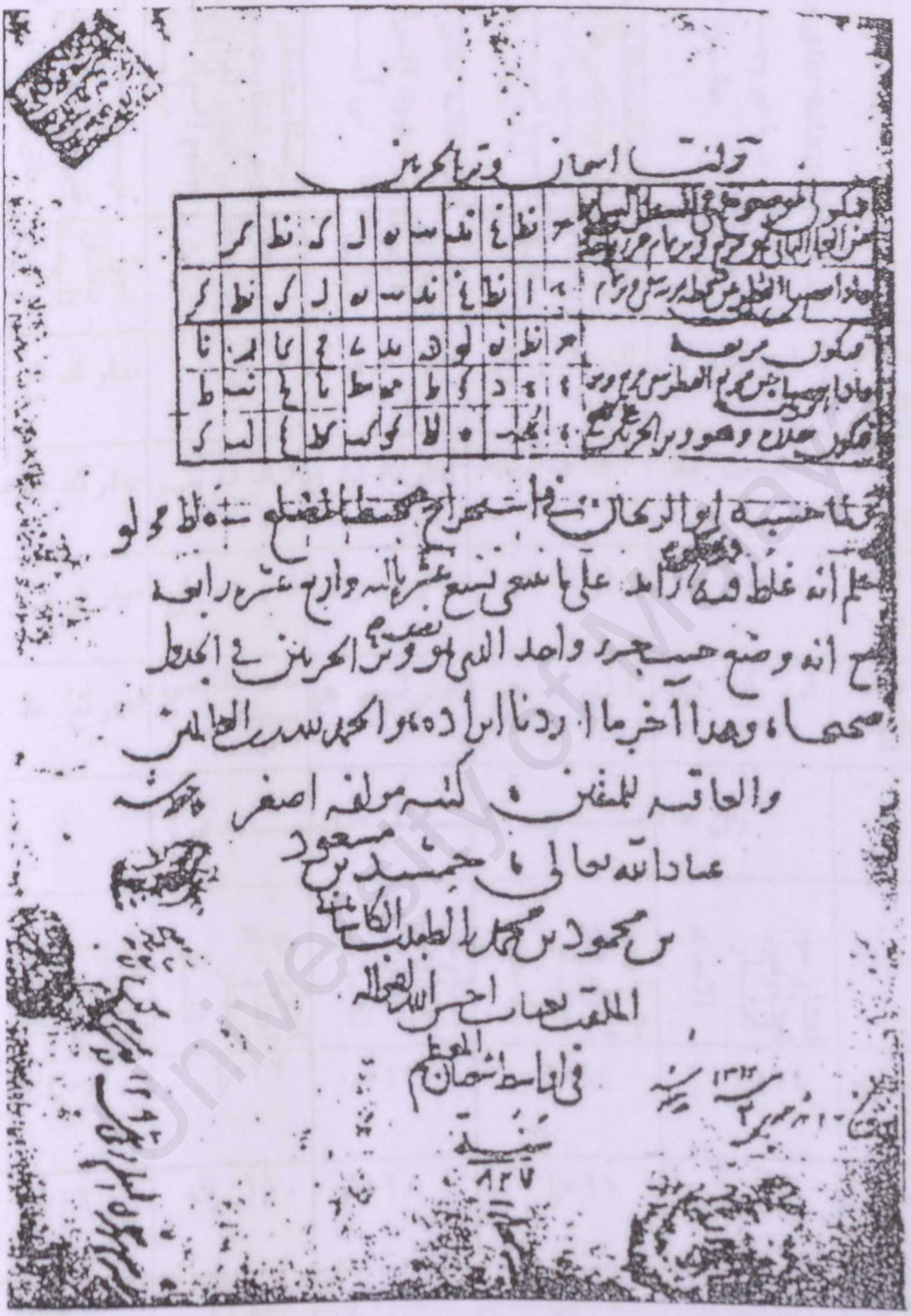


Figure A.1: End page of al-Kashi book "key of Arithmetic" (Memarian 1988)

	اجزاء دقائق ثانیه ها ثوالث — اگر دهانه طاق در این ضرب شود مقعر وجه طاق حاصل شود.	اجزاء دقائق ثانیه ها ثوالث — اگر ضخامت طاق در این ضرب شود و حاصل با مقعر طاق جمع شود و حاصل را در ضخامت طاق ضرب کنیم سطح جبهه طاق بدست می آید.	اجزاء دقائق ثانیه ها ثوالث — اگر دهانه طاق در این ضرب شود افراز طاق بدست می آید.	اجزاء دقائق ثانیه ها ثوالث — اگر ضخامت طاق در این ضرب شود ضخامت مقدم و افراز اول را با این طاق بدست می آید.	اجزاء دقائق ثانیه ها ثوالث — موجسم دهانه طاق را در این ضرب کنیم سطح مجسم طاق بدست می آید.
در روش اول	ا لر کو و	اه لر کح	مفر لد برا	اا نح د	صفر کد کح مت
در روش دوم	الطب مط	اه نه مب	صفر له نه مو	اهـ نه س	صفر کد طصد
در روش سوم	اسه صد حـ	الو کا ص	صفر لح ر ل	د و ~ لح	صفر کو ب لد
در روش چهارم	امه کو نو	الد لد هو	صفر لحه هو	کانت الثانی بمینه اهنه	صفر کح ما ما
	وآن مقادیر به ارقام هندی				
	الاحاد اعشار اعشار دوم اعشار سوم	الاحاد اعشار اعشار دوم اعشار سوم	الاحاد اعشار اعشار دوم اعشار سوم	الاحاد اعشار اعشار دوم اعشار سوم	الاحاد اعشار اعشار دوم اعشار سوم
در روش اول	۱٫۶۲٤	۱٫۵۹٤	۰٫۵٦۹	۱٫۰۳۳	۰٫٤۰۸
در روش دوم	۱٫٦۵۱	۱٫۵۹۹	۰٫۵۹۸	۱٫۰۹۹	۰٫٤۱۹
در روش سوم	۱٫۷۱۲	۱٫٦۰٦	۰٫٦۳۸	۱٫۱۱۵	۰٫٤۰۱
در روش چهارم	۱٫۷۵۷	۱٫۵۷٦	۰٫٦٤۵	۱٫۰۹۰	۰٫٤۷۸

(جدول ـ ۱)

Figure A. 2: Table 1 about the distinct elements of arch, translated from Italian, Russian, and Arabic from of the al-Kashi book ' key of Arithmetic' by Memarian (1988).

(جدول ـ ۲)

Figure A. 3: Table 2 about the distinct elements of arch, translated from Italian, Russian, and Arabic from of the al-Kashi book ' key of Arithmetic' by Memarian (1988).

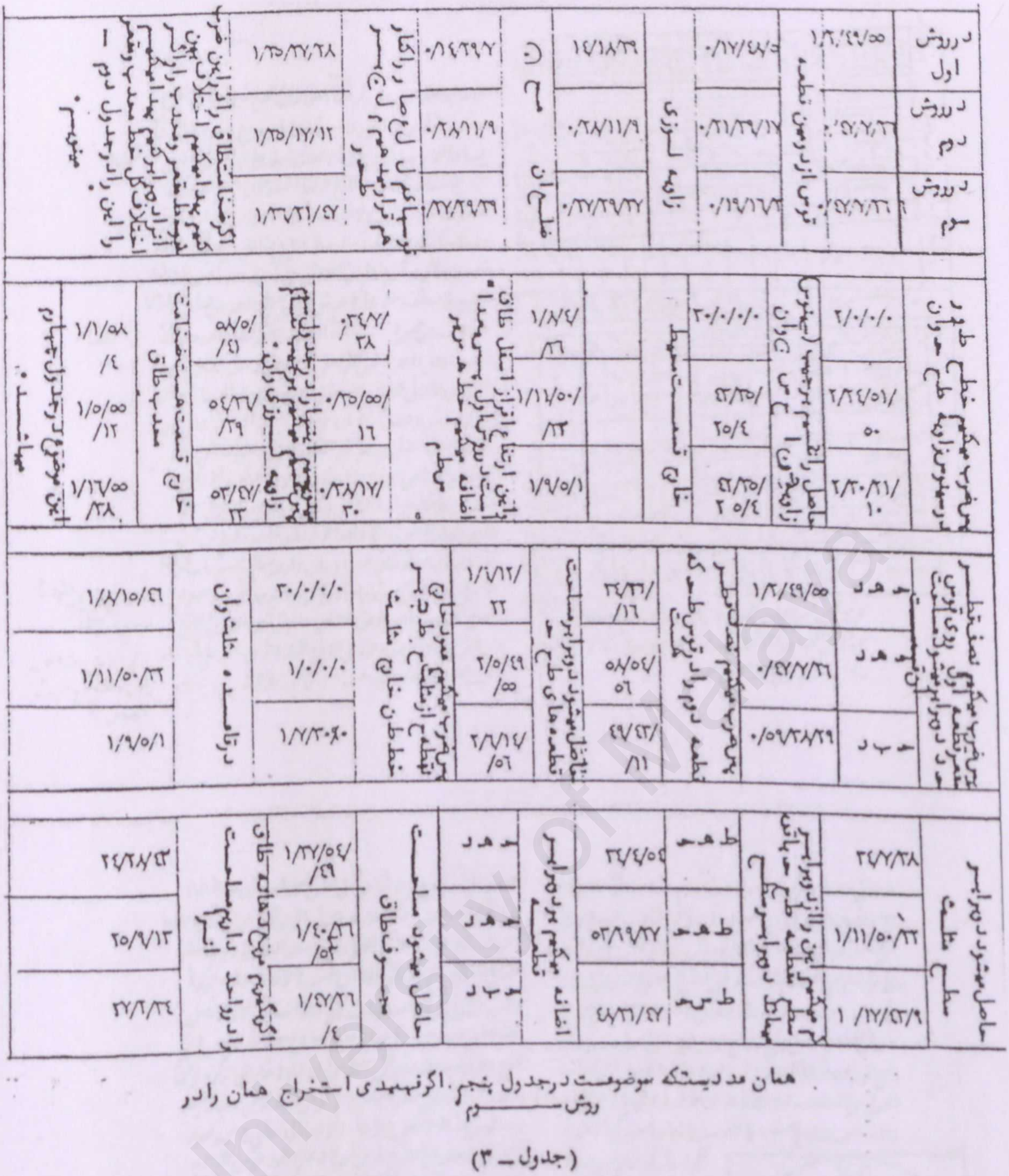
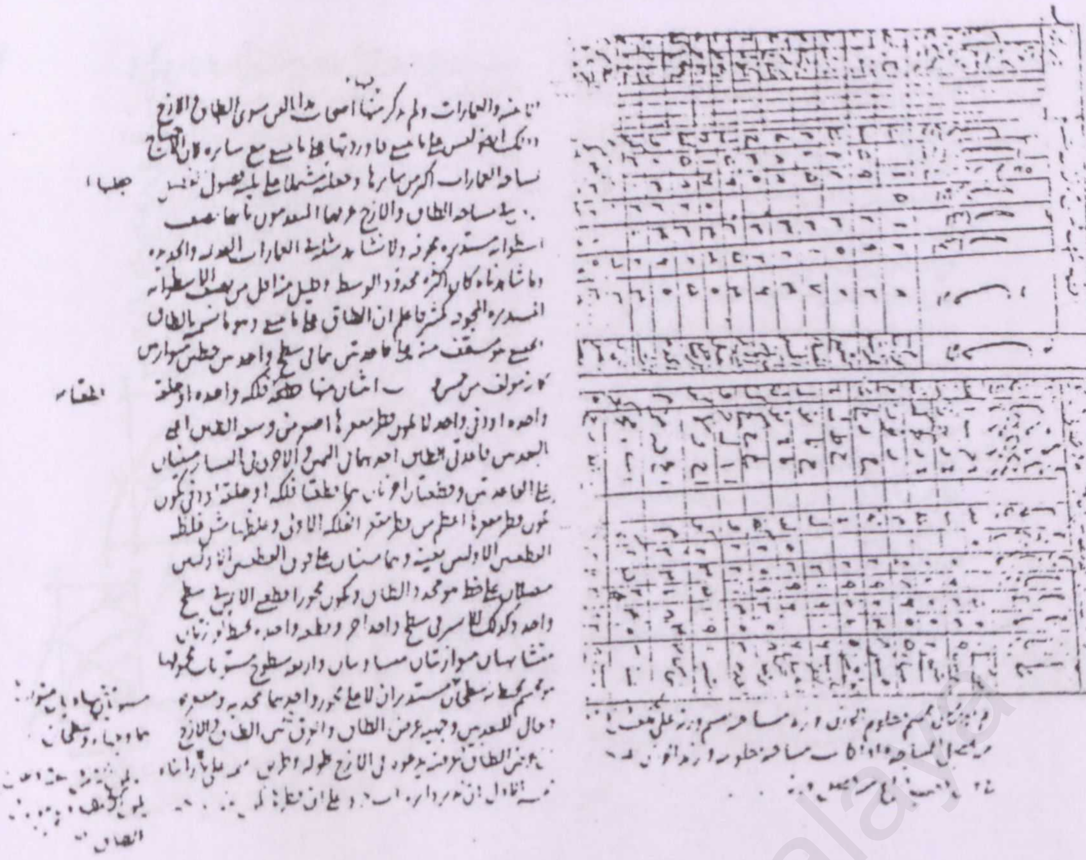


Figure A. 4: Table 3 about the distinct elements of arch, translated from Italian, Russian, and Arabic from of the al-Kashi book ' key of Arithmetic' by Memarian (1988).



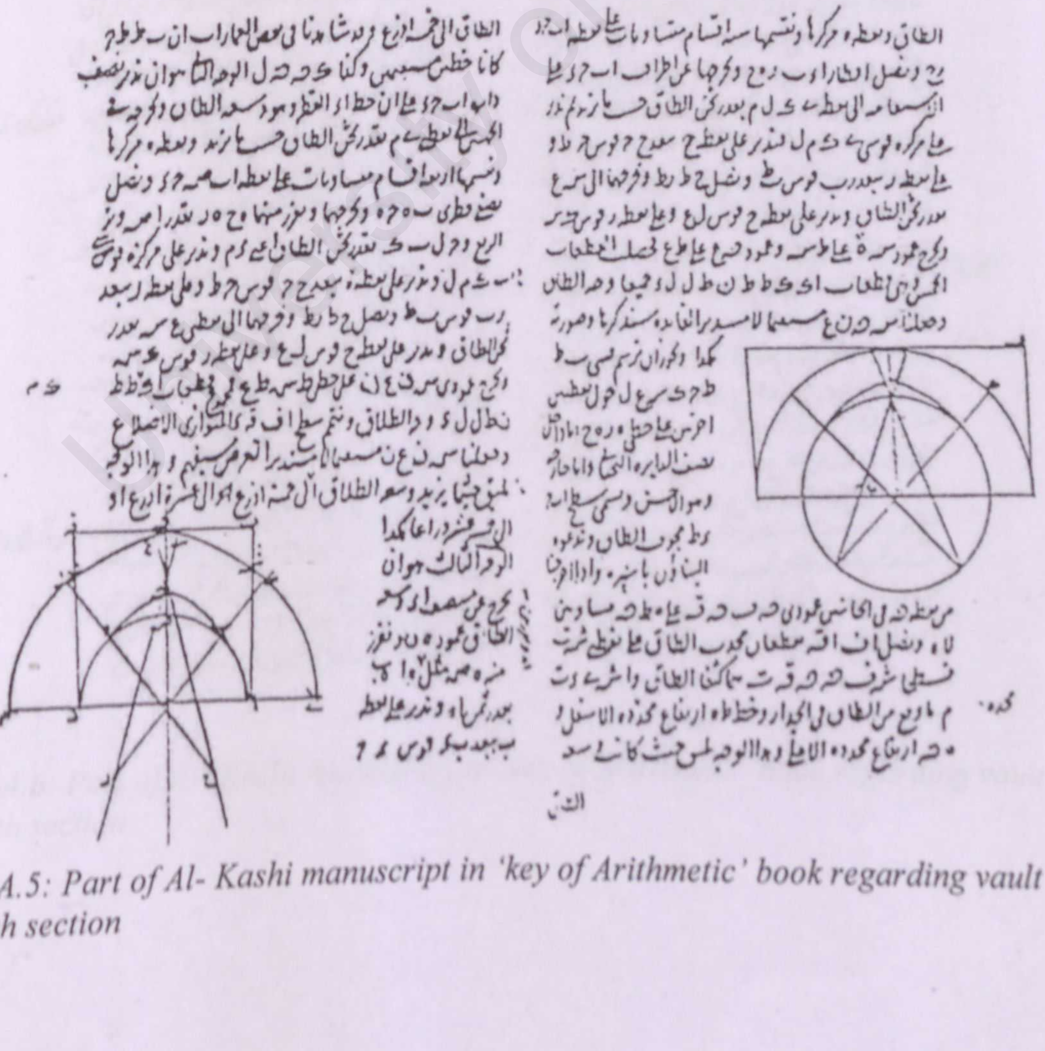


Figure A.5: Part of Al- Kashi manuscript in 'key of Arithmetic' book regarding vault and arch section

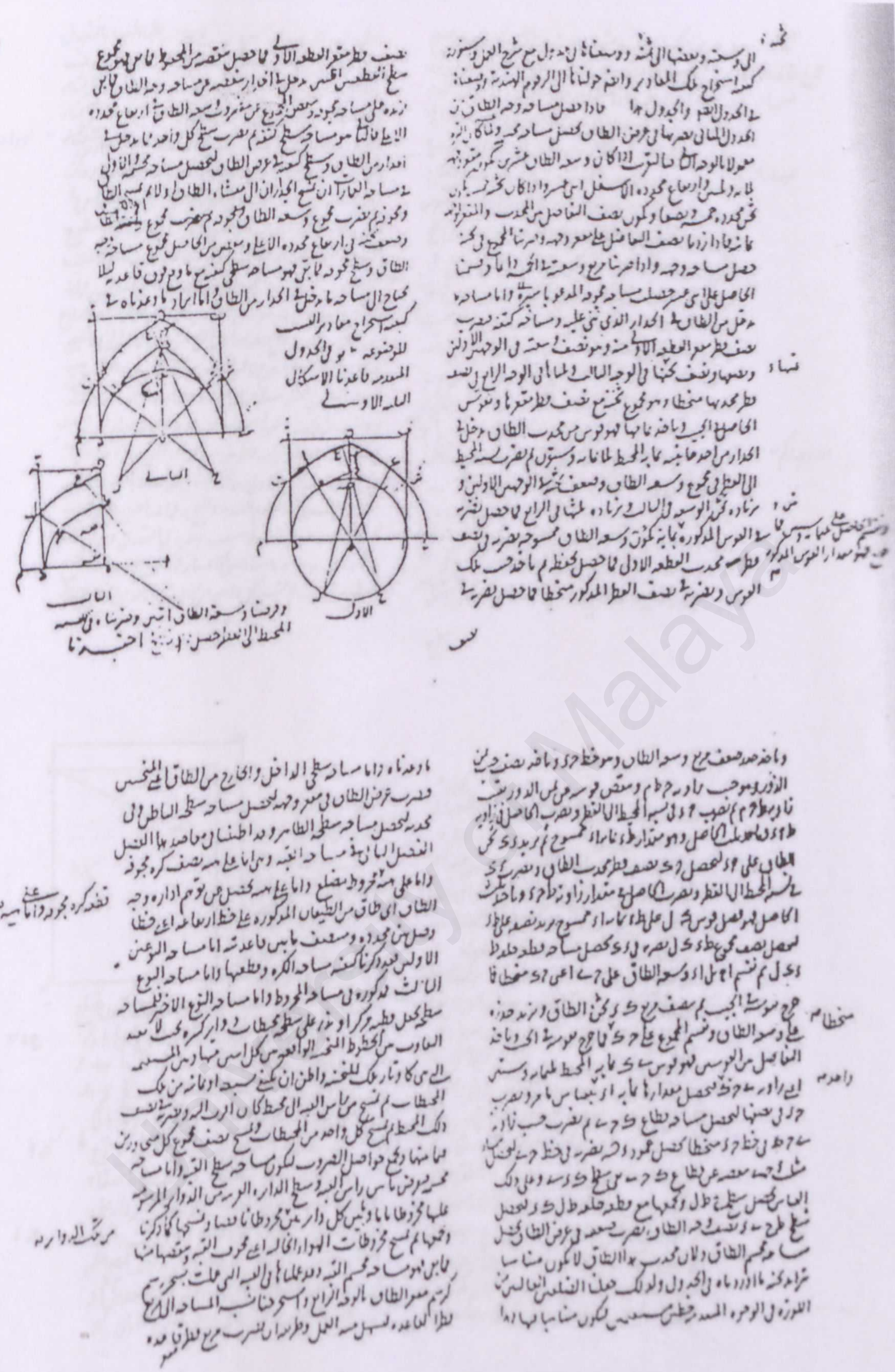
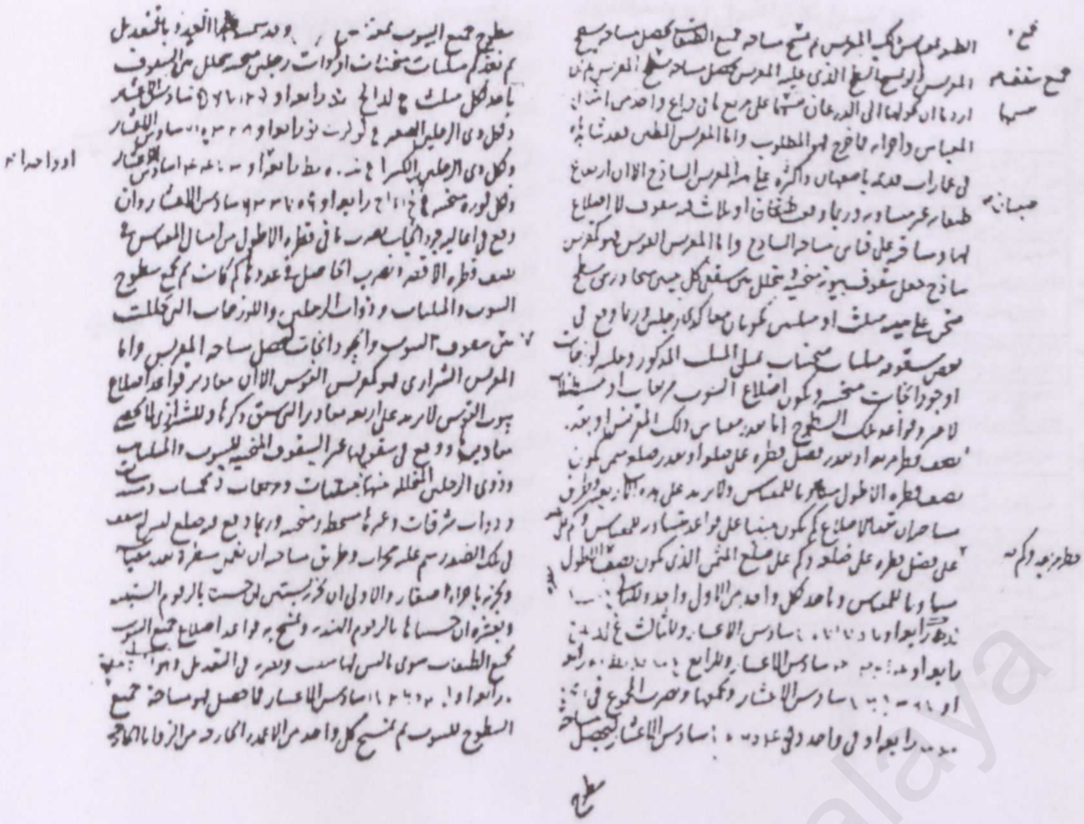


Figure A.6: Part of Al- Kashi manuscript in 'key of Arithmetic' book regarding vault and arch section



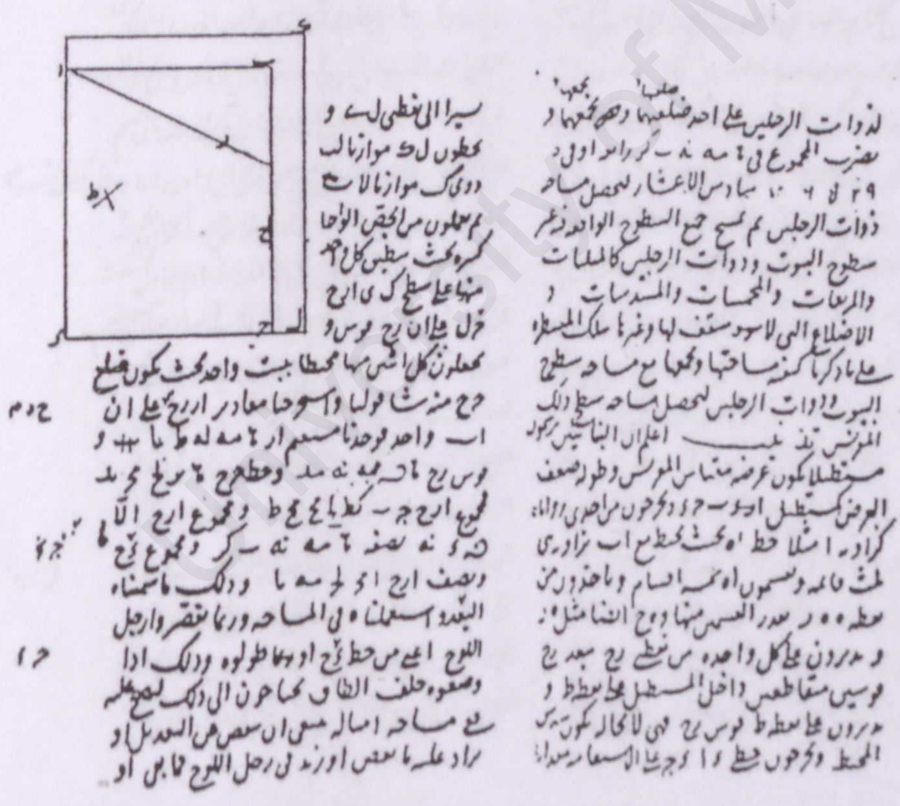


Figure A.7: Part of Al- Kashi manuscript in 'key of Arithmetic' book regarding vault and arch section.

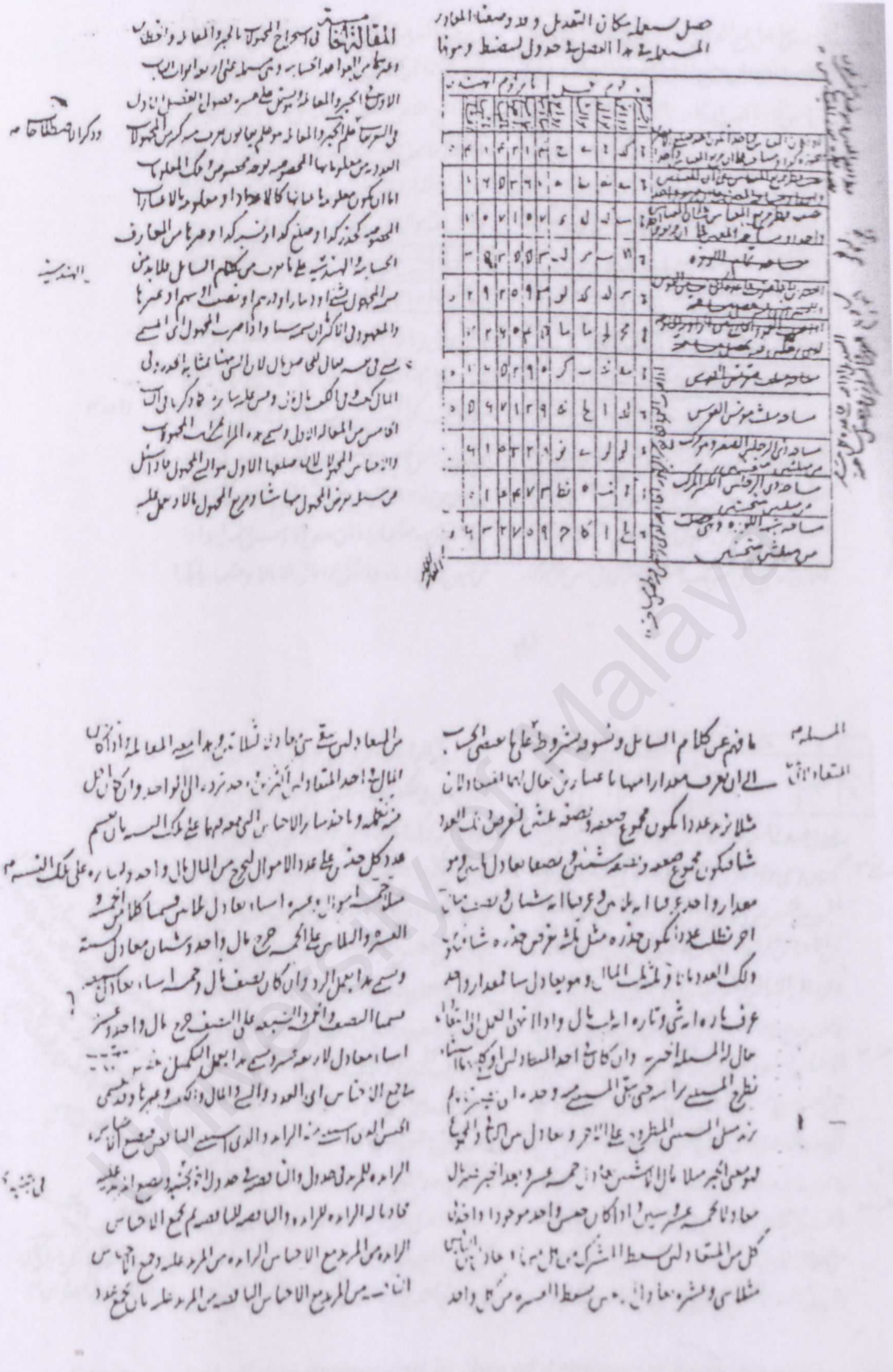


Figure A.8: Part of Al- Kashi manuscript in 'key of Arithmetic' book regarding vault and arch section

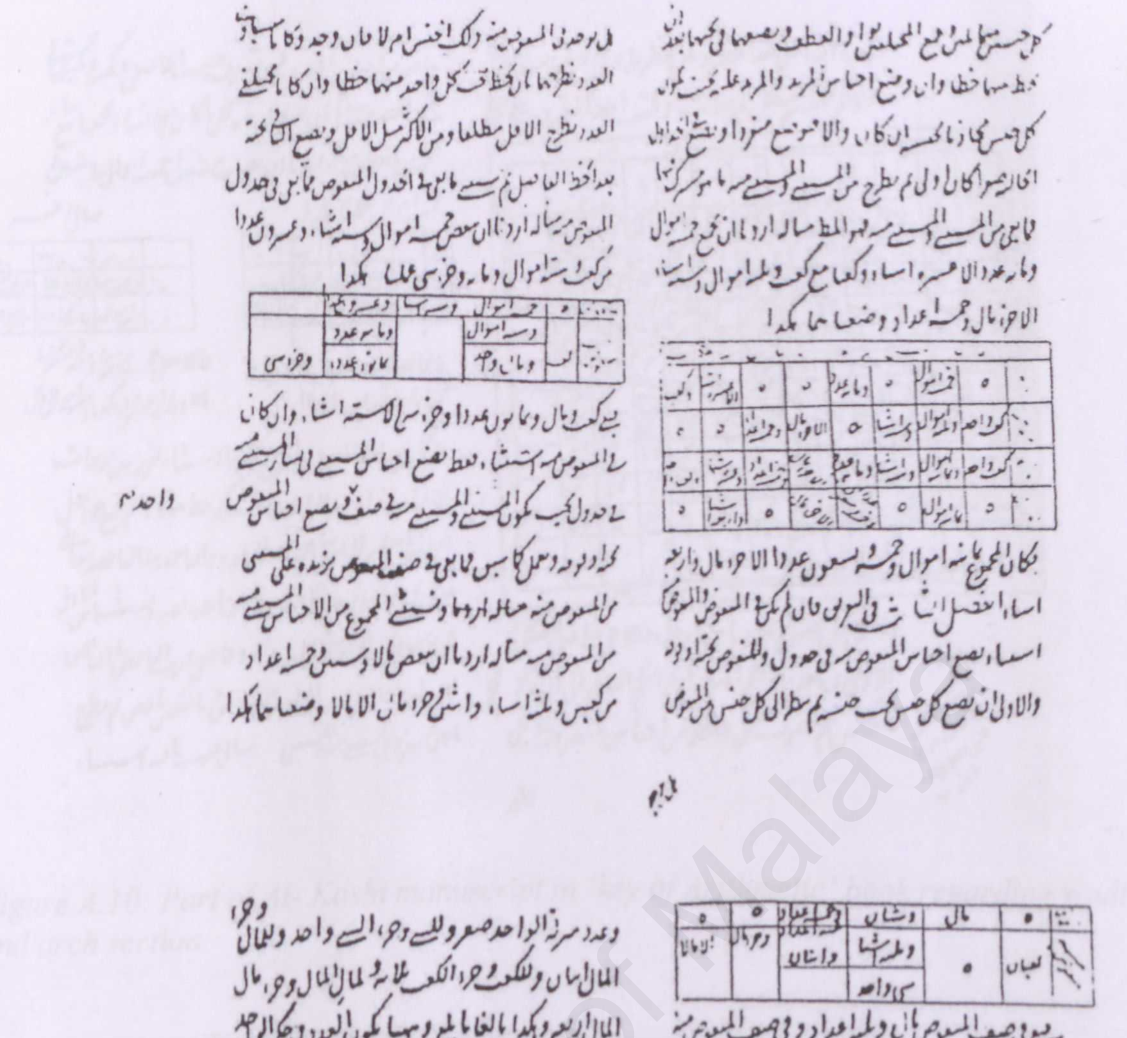


Figure A.9: Part of Al- Kashi manuscript in 'key of Arithmetic' book regarding vault and arch section

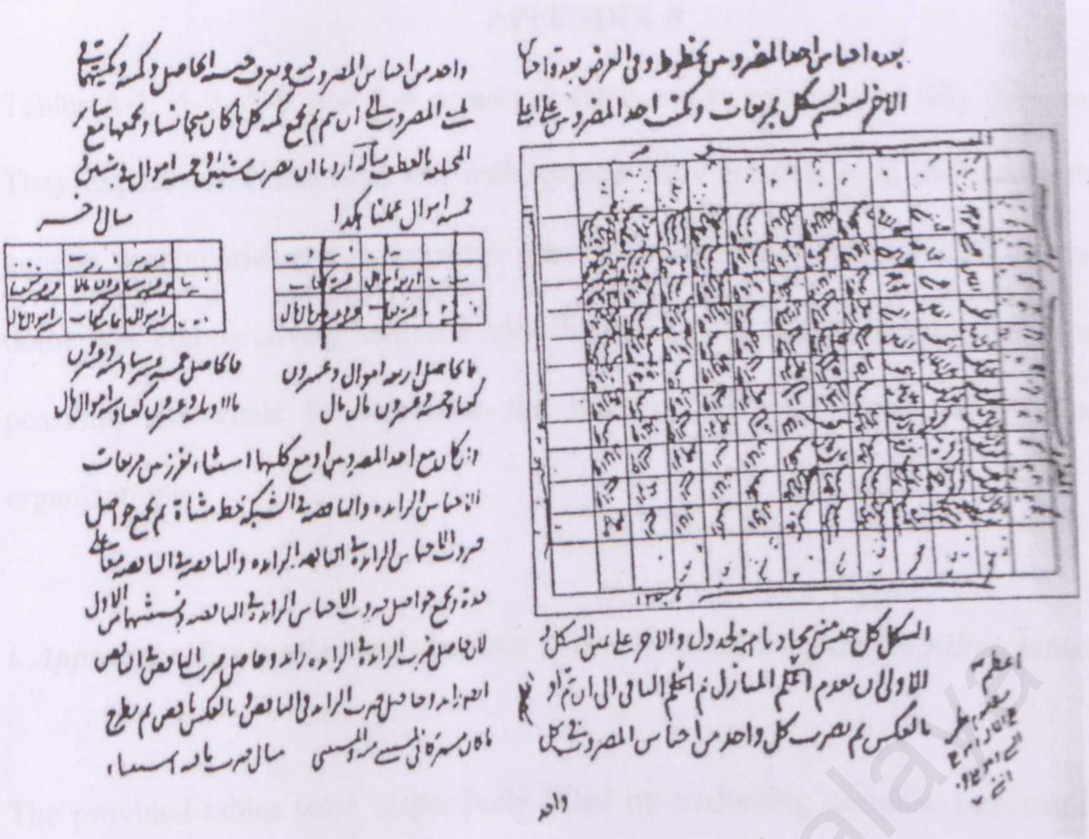


Figure A.10: Part of Al- Kashi manuscript in 'key of Arithmetic' book regarding vault and arch section

	بالرقوم الجمل					بالرقوم الهندي						
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
إذا كان المقياس واحدا يكون أحد ضلعي الأقصر للوزة كذا ومساحته على أن مربع المقياس واحد	صفر	كد	نا	ى	ح	٤	١	٢	٤	١	٤	٠
قطر أقصر المعين وهو ضلع مثمن يكون نصف قطره بقدر المقياس	صفر	مه	نه	نط	نه	٧	٦	٣	٥	٦	٧	
نصف قطر مربع المقياس على أن المقياس واحد ومساحة المعين على أن مربعه واحد	صفر	مس	كه	له	ى	٧	٠	١	٧	٠	٧	
نصفه مساحة المعين	صفر	بكا	س	مر	ل	٣	٥	٥	٣	٥	٣	
مساحة تمام اللوزة	صفر	ير	لد	كد	نو	٣	٩	٠	٢	٩	٢	٠
التعديل إذا ضرب قاعدة كل بيت من اللوزة والشيرازي فيه حصل مساحته	١	مح	لح	مه	ما	٥	٤	٠	٦	٢	٧	١
إذا ضرب العمود الخارج من الزاوية الخارجة لذي رجلين فيه يحصل مساحته	صفر	مه	نه	ب	كر	٠	٩	٢	٥	٦	٧	٠
مساحة مثلث مقرنس القوس	صفر	لد	١	لح	نه	٩	٢	١	٧	٦	٥	٠
مساحة ذي الرجلين الصغير وهو مركب من مثلثين متحنيين	صفر	لو	لز	ى	نو	٨	٢	٢	٠	١	٦	٠
مساحة ذي الرجلين الكبير المركب من مثلثين متحنيين	١	صفر	نب	هـ	نط	٣	٧	٤	٤	١	٠	١
مساحة شبه اللوزة وهي حاصلة من مثلثين متحنيين	صفر	لح	١	كا	حـ	٩	٠	٧	٣	٣	٦	٠

(١) أضفنا الحساب الستيني لتوضيح رقوم الجمل . (٢) ل ث قصر . (٣) ل ل يزاد .

Figure A.11: Table of muqarnas calculation from 'key of Arithmetic' book by two Egyptian masters Cairo, 1967.

APPENDIX B

Tables A-1, A-2, A-3, and A-4 contained detail analysis process of fifty three samples. They expose brief historical and architectural back grounds with evaluating the four generic vocabularies and two general grammars' aspects of those studied domes. Each dome was comparatively analyzed according to its plans, photographs, and, whenever possible, site visits to determine the relative levels of architectonic conceptual organizations.

i. Approach: Evaluation and Analysis of the Domical Samples for filling tables

The provided tables were respectively filled by evaluating samples, comparatively, in each defined zone. In comparing process, the samples of each region were compared together regarding the kinds of vocabularies exited in their compositions. In addition, in terms of expressing the qualitative assessments, specific sign was used (●).

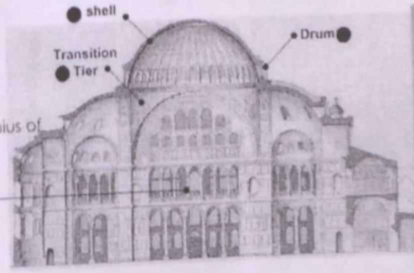
In terms of incomplete information about samples, the sign of question mark (?) was used beside those circular signs, whenever the information of samples was incomplete. In order to underline the conical domes, the sign of (A) was used beside the circular sing of shell vocabulary. These estimations had been ranked in the specific tables for quantitative estimations.

Following tables included brief historical and architectural backgrounds of fifty three samples and also information of their vocabularies and grammar analysis information. This derived issued have been collected in the provided table 4.3 in order to estimate their distributions.

Table B.1: Illustrations on case studies in zone I: Turkey region.

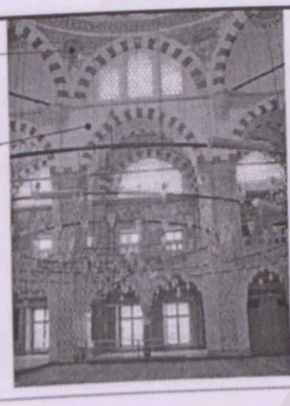
Turkey Region

Variant Names: Sancta Sophia, Sancta Sapientia, Hagia Sophia
Location: Istanbul, Turkey
Architect(s): Isidore of Miletus and Anthemius of Tralles
Date: 532-537 A.D.
Style/Period: 6th Byzantine
Building Type: Religious
Building Usage: Church, Mosque



1 Dome Typology: Simple with drum

Variant Names: Rüstem Pasha Mosque , ' Rüstem Pasha Camii'
Location: Istanbul, Turkey
Architect(s): Mimar Sinan
Date: 1555-1620 A.D.
Style/Period: Iznik, Centuries 15th-16th
Building Type: Religious
Building Usage: Mosque

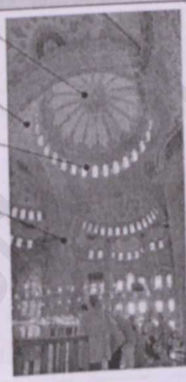


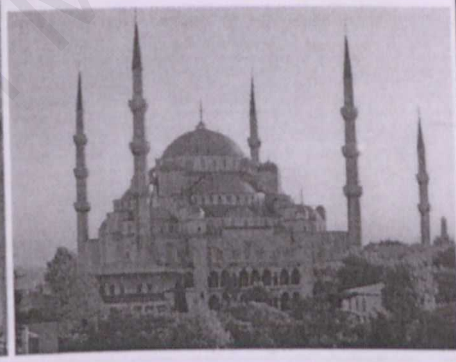
2 Dome Typology: Simple with drum

A Conical shell ? Insufficient information

Turkey Region

Variant Names: Sultanahmet mosque (Camii)
Location: Istanbul, Turkey
Architect(s): Sedefhar Mehmet Ağa
Date: 1609-1616 .A.D.
Style/Period: Ottoman -Century 16th
Building Type: Religious
Building Usage: Mosque





3 Dome Typology: Simple with drum

Variant Names: Ulu Camii, Malatya Ulu Camisi, Camii Kebir, great mosque of Malatya
Location: Malatya, Turkey
Date: 1224 or 1247 A.D.
Style/Period: Seljuk, 12th
Building Type: Religious
Building Usage: Mosque

4 Dome Typology: Simple with drum

A Conical shell ? Insufficient information

Table B.1: Illustrations on case studies in zone I :Turkey region (Continued).

Turkey Region

5

Variant Names: Green mosque, Yesil Cami, Mosque of Mehmed I

Location: Bursa, Turkey

Architect/Planner: Haci Ivaz Pasa

Client: Mehmed I

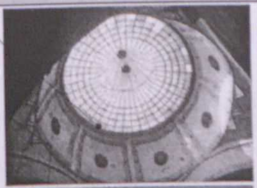
Date: 1419-1421 A.D.

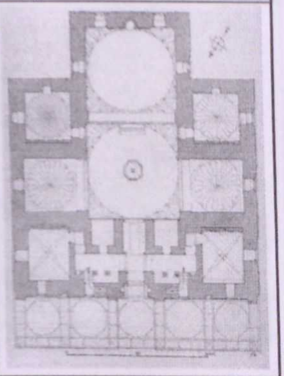
Style/Period: Ottoman, Century 15th

Building Type: Religious

Building Usage: Mosque

Dome Typology: Simple with drum





6

Variant Names: Old mosque of Edirne, Eski Cami

Architects: Haci Alaeddin, Ömer bin Ibrahim

Client: Emir Süleyman, Mehmed I

Location: Edirine, Turkey

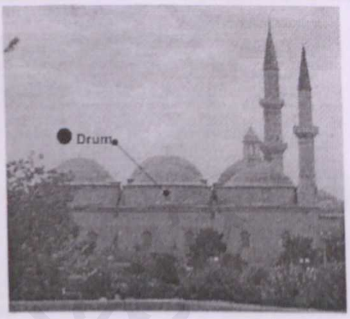
Date: 1402-14 A.D.

Style/Period: Ottoman, 15th

Building Type: Religious

Building Usage: Mosque

Dome Typology: Simple with drum



A Conical shell ? Insufficient information

Turkey Region

7

Variant Names: Sehzade Mosque, Şehzade Camii

Location: Istanbul, Turkey

Architect(s): Mimar Sinan

Date: 1548 A.D.

Style/Period: Ottoman -Century 16th

Building Type: Religious

Building Usage: Mosque

Dome Typology: Simple with drum

8

Variant Names: Suleymaniye mosque, Süleymaniye Camii

Architect: Mimar Sinan

Location: Mazar-e Sharif, Turkey

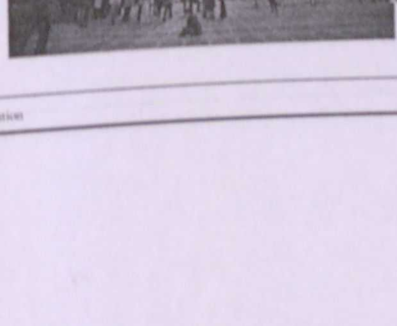
Date: 1557 A.D.

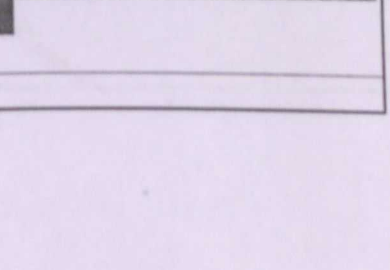
Style/Period: Ottoman -Century 16th

Building Type: Religious

Building Usage: Mosque

Dome Typology: Simple with drum





A Conical shell ? Insufficient information

Table B.1: Illustrations on case studies in zone I :Turkey region (Continued).

Turkey Region

9

Variant Names: Bayezid II Mosque, Beyazidye Camii'

Location: Istanbul, Turkey

Architect: Mimar Sinan

Date: 1506 A.D.

Style/Period: Ottoman, Century 16 th

Building Type: Religious

Building Usage: Mosque

Dome Typology: Simple with drum

shell

Drum

Transition Tier

Load Bearing system

10

Variant Names: Mihrimah Sultan Camii, Mihrimah mosque

Architect: Mimar Sinan

Location: Istanbul, Turkey

Date: 1565 A.D.

Style/Period: Ottoman, 16th

Building Type: Religious

Building Usage: Mosque

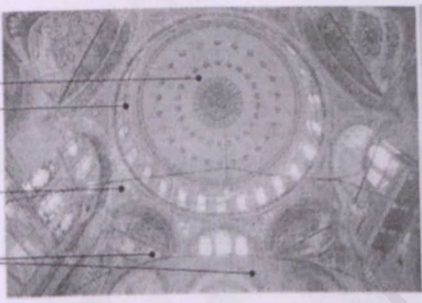
Dome Typology: Simple with drum

shell

Drum

Transition Tier

Load Bearing system



A Conical shell   ? Insufficient information

Turkey Region

11

Variant Names: Great Mosque of Manisa,Manisa Ulu Cami, Manisa, Ishak Bey Mosque, Ishak Çelebi Külliyesi

Location: Manisa, Turkey

Client: Saruhanoglu Ishak Çelebi

Date: 1366-67A.D.

Style/Period: Saruhan Emirate, Century 14th

Building Type: Religious

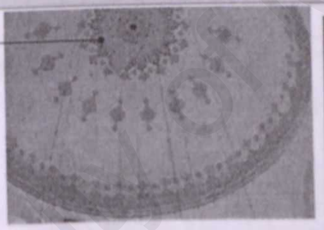
Building Usage: Mosque

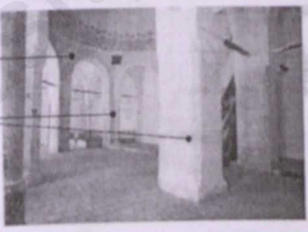
Dome Typology: Simple with drum

shell

Transition Tier

Load Bearing system





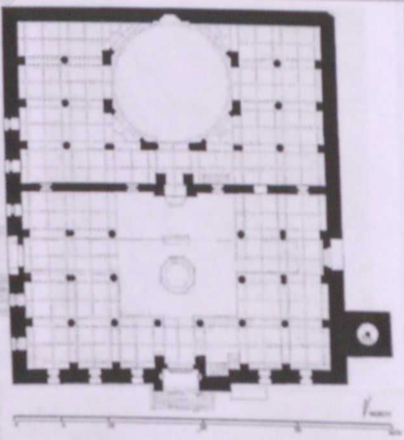


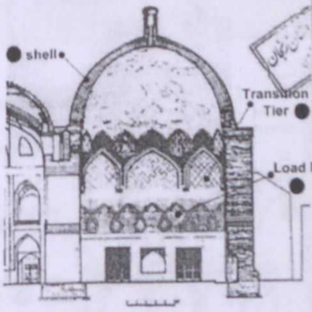
Table B.2: Illustrations on case studies in zone II: Iran and Iraq regions.

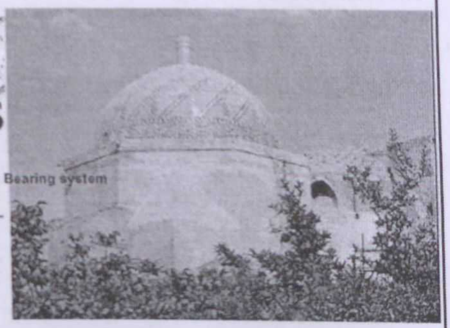
Iran Region

1

Variant Names: Masjid-e Jame, Congregational Mosque, Jame Kabir
Location: Qazvin, Iran
Date: 1106-1115 A.D.
Style/Period: Seljuk, Century 12th
Building Type: Religious
Building Usage: Mosque

Dome Typology: Simple without drum

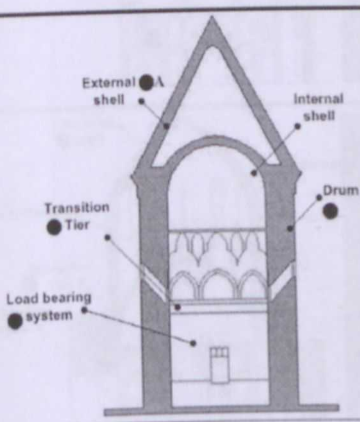




2

Variant Names: Amineh Khatun Shrine, Hamd-allah Mustawfi Tomb
Location: Qazvin, Iran
Date: ca. 1340 A.D.
Style/Period: Ilkhanid 14th
Building Type: Funerary
Building Usage: Tomb

Dome Typology: Simple with drum



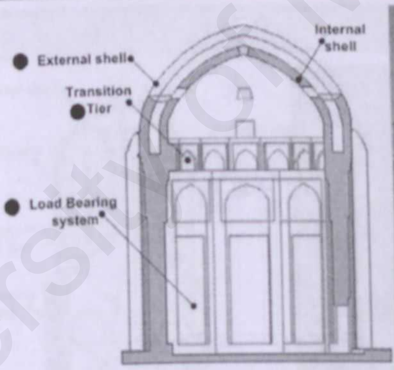
A Conical shell ? Insufficient information

Iran Region

3

Variant Names: Twin towers of Kharraqan
Location: Qazvin, Iran
Date: 1067 and 1093 A.D.
Style/Period: Seljuk, Century 12th
Building Type: Funerary
Building Usage: Mausoleum

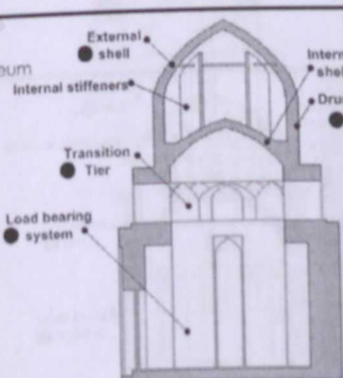
Dome Typology: Simple without drum



4

Variant Names: Sultan Bakht Agha Mausoleum
Location: Isfahan, Iran
Date: 1391 A.D.
Style/Period: Muzaffarid
Building Type: Funerary
Building Usage: Tomb

Dome Typology: Compound with drum



A Conical shell ? Insufficient information

Table B.2: Illustrations on case studies in zone II: Iran and Iraq regions (Continued).

Iran Region

5

Variant Names: Shah mosque, Masjid-e Imam

Location: Isfahan, Iran

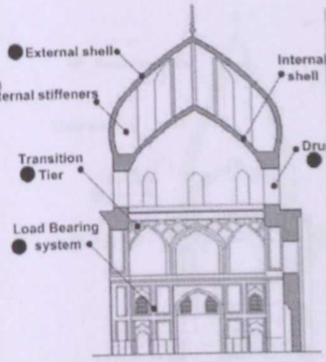
Date: 1611- ca. 1638 A.D.

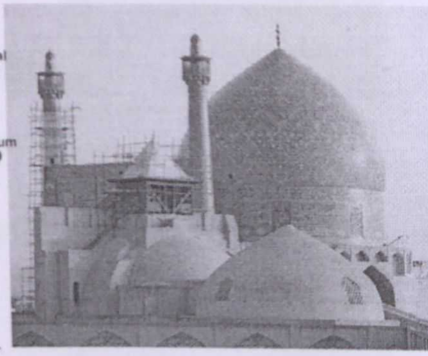
Style/Period: Safavid, Century 17th

Building Type: Religious

Building Usage: Mousqe

Dome Typology: Compound with drum





6

Variant Names: chahar Bagh madrasa ,Madar-e shah madrasa

Location: Isfahan, Iran

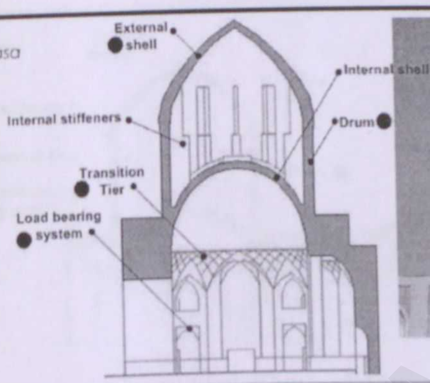
Date: 1706- 1714 A.D.

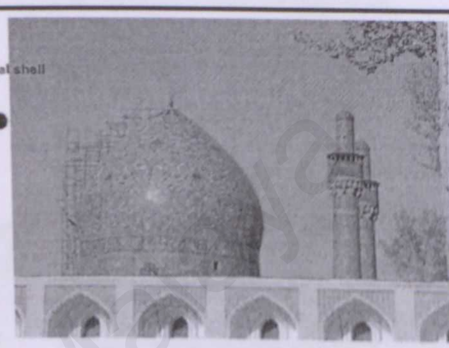
Style/Period: Safavid ,18th

Building Type: Religious

Building Usage: Madrasa, School

Dome Typology: Compound with drum





A Conical shell ? Insufficient information

Iran Region

7

Variant Names: Holy Shrine of Ali Riza, 'Ali al-Rida Shrine, 'Ali al Rida Shrine, , Astan Quds Razavi, Astan-e Qods-e Razawi

Location: Mashhad, Iran

Date: 14th -ca. 20th

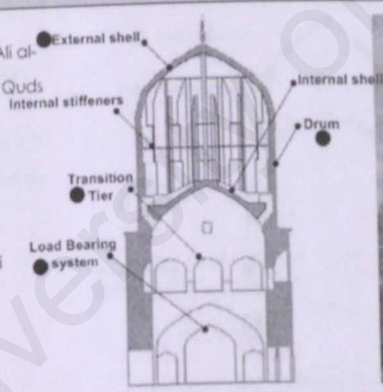
Style/Period: Timuird , Century 15th

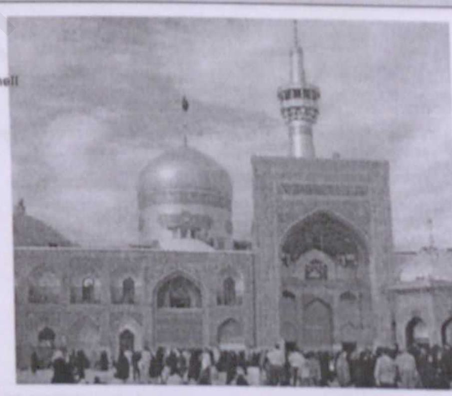
Architect/Planner: Qavam al-Din Shirazi

Building Type: Funerary, Religious

Building Usage: Tomb, Shrine

Dome Typology: Compound with drum





8

Variant Names: Masjid-i Mir Chaqmaq, Mir Chaqmaq Mosque Complex

Location: Yazd, Iran

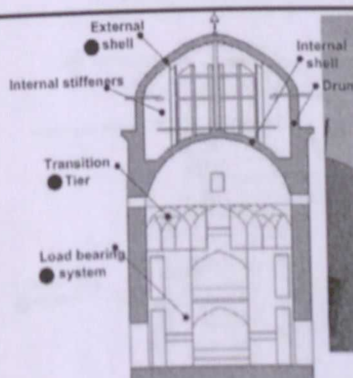
Date: 1437 A.D.

Style/Period: Timurid, Century 15th

Building Type: Religious

Building Usage: Mosque

Dome Typology: Compound with drum



A Conical shell ? Insufficient information

Table B.2: Illustrations on case studies in zone II: Iran and Iraq regions (Continued).

Iran Region

9

Variant Names: Bayazid Bistami shrine

Location: Bastam, Iran

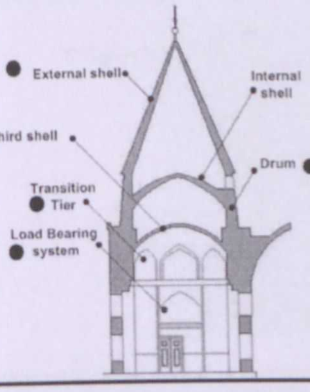
Date: 1120-1300 A.D.

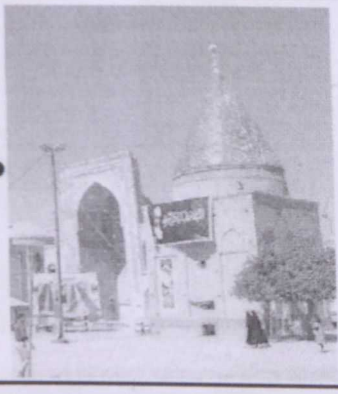
Style/Period: Seljuk 12th / Timurid 15th

Building Type: Funerary

Building Usage: Mausoleum

Dome Typology: Compound with drum





10

Variant Names: Amin-edin Jebrail tomb

Location: Ardebil, Iran

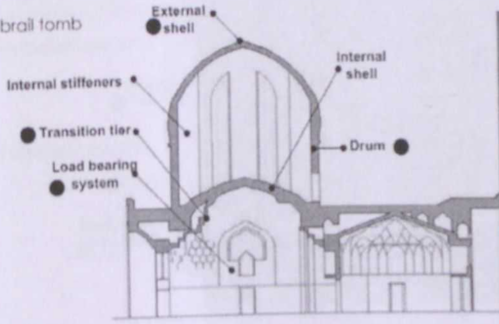
Date: 1380-ca.1700 A.D.

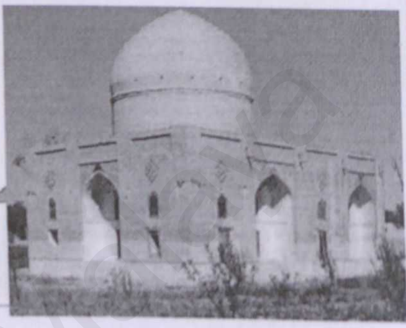
Style/Period: Ilkhanid 14th Safavid 17th

Building Type: Funerary

Building Usage: Tomb

Dome Typology: Compound with drum





A Conical shell ? Insufficient information

Iran Region

11

Variant Names: Nureddin Nimat Allah mausoleum, Shrine of Shaykh Ni'matullah

Location: Kerman, Iran

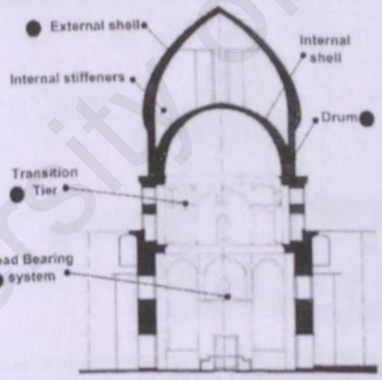
Date: 1437 (Safavid reconstruction 1601) A.D.

Style/Period: Qajar, Safavid, Timurid ,Centuries 15th , 17th , 19th

Building Type: Funerary, Religious

Building Usage: Tomb, Shrine

Dome Typology: Compound with drum



12

Variant Names: Sultani (Imam) madrasa

Location: Kashan, Iran

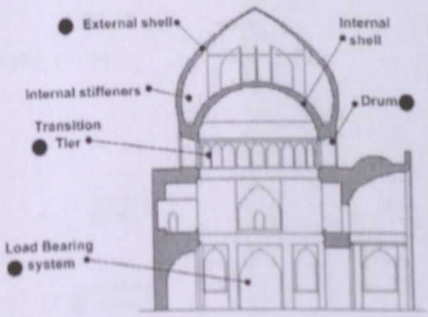
Date: 1848 A.D.

Style/Period: Safavid, Century 17th

Building Type: Religious

Building Usage: School

Dome Typology: Compound with drum



A Conical shell ? Insufficient information

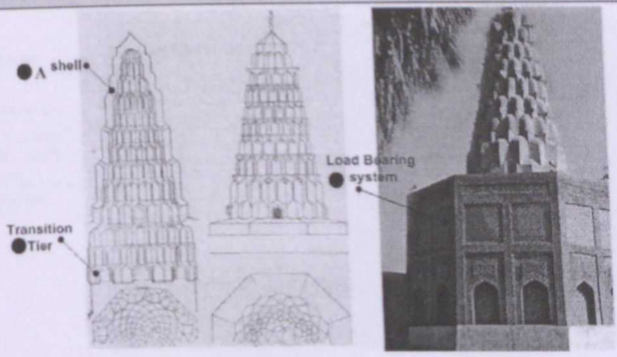
Table B.2: Illustrations on case studies in zone II: Iran and Iraq regions (Continued).

Iraq Region

1

Variant Names: Sitt Zubaydah Tomb, Tomb of Sitt Zubaida Turba, Mausoleum of Zumurrud Khatun
Location: Baghdad, Iraq
Date: ca. 1193 A.D.
Style/Period: Abbasid, Century 12th
Building Type: Funerary
Building Usage: Tomb

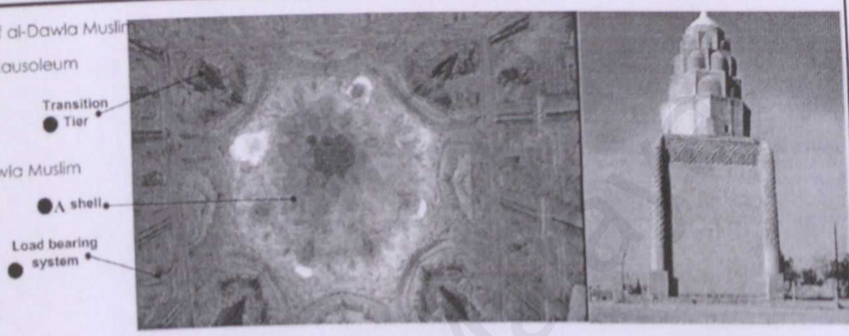
Dome Typology: Simple without drum



2

Variant Names: Mausoleum of Sharaf al-Dawla Muslim 'Uqaylid ruler of Mosul, Imam Dur Mausoleum
Location: Samarra, Iraq
Date: 1085 A.D.
Client: 'Uqaylid amir, Sharaf ad-Dawla Muslim
Style/Period: Uqaylid, 11th
Building Type: Funerary
Building Usage: Tomb

Dome Typology: Simple without drum



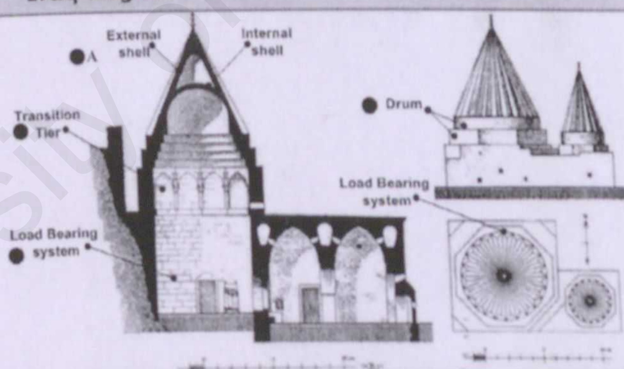
A Conical shell ? Insufficient information

Iraq Region

3

Variant Names: Shaikh Adi (Sheikh 'Adi) Mausoleum and Shrine
Location: Shaykh 'Adi, Iraq
Date: 12th to 14th ca. A.D.
Style/Period: Seljuk, Century 12th
Building Type: Religious, Funerary
Building Usage: Shrine, Mausoleum

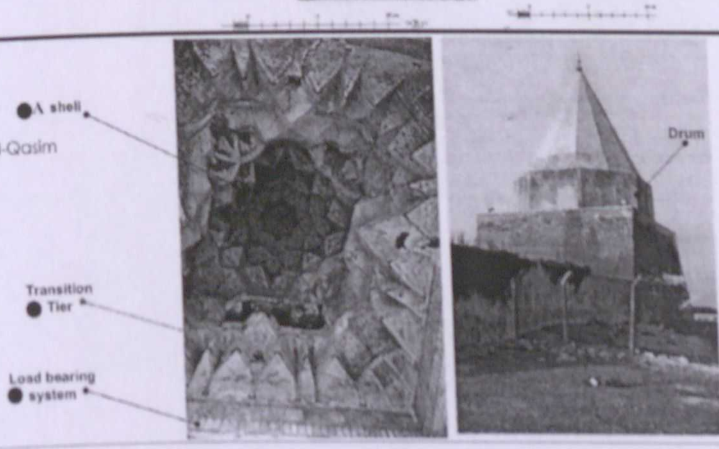
Dome Typology: Simple with drum



4

Variant Names: Mashhad of Imam Yahaya ibn al-Qasim
Location: Mosul, Iraq
Client: Badr al-Din Lu'lu'
Date: 1239 A.D. Century 13th
Building Type: Funerary
Building Usage: Mausoleum

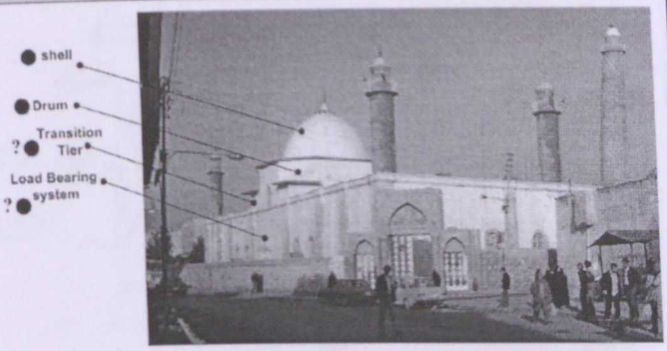
Dome Typology: Simple with drum



A Conical shell ? Insufficient information

Table B.2: Illustrations on case studies in zone II: Iran and Iraq regions (Continued).

Iraq Region	
5	***Variant Names:*** al-Hadba, Minaret of the Great Mosque of Nur al-Din, Great mosque of Nur al-Din ***Client:*** Abu'l Qasim al-Malik al-'Adil Nur al-Din Mahmud ibn Zangi (known as Nur al-Din) ***Location:*** Mosul, Iraq ***Date:*** 1170-1172 A.D. ***Style/Period:*** Zangid, Century 12th ***Building Type:*** Religious ***Building Usage:*** Mosque **Dome Typology: Simple with drum**



Λ Conical shell ? Insufficient information

Table B.3: Illustrations on case studies in zone III: Afghanistan and Pakistan regions.

Afghanistan Region

1

Variant Names: Khvaja Abou Nasr Parsa Mausoleum, Ziarat-i Khoja Abu Nasr Parsa, Khodja Abu Nasr Parsa Ziarat, Khvajeh Abu Nasr Parsa Ziyarat.

Location: Balkh, Afghanistan

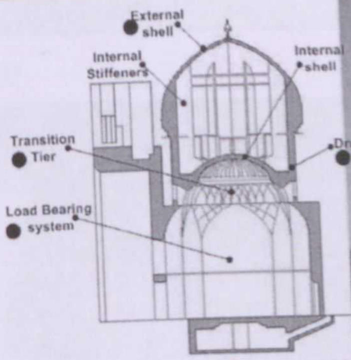
Date: between 1460 and 1598, Centuries 15th, 16th

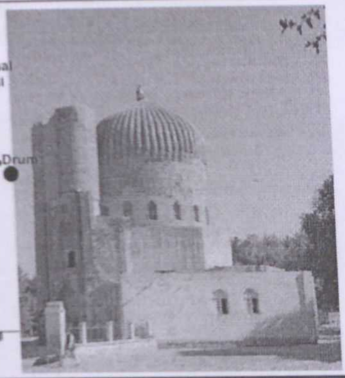
Style/Period: Timurid, Century 15th

Building Type: Funerary

Building Usage: Tomb, Shrine

Dome Typology: Compound with drum





2

Variant Names: Kohsan mausoleum

Location: Herat, Afghanistan

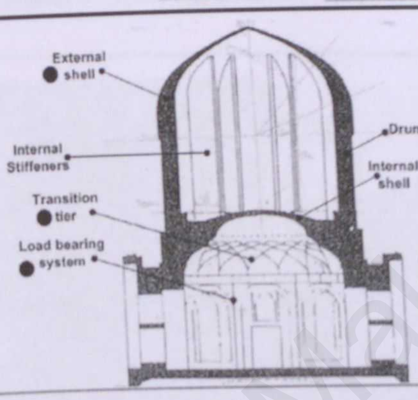
Date: 1436 A.D.

Style/Period: Timurid, Century 15th

Building Type: Funerary

Building Usage: Tomb, Shrine

Dome Typology: Compound with drum



A Conical shell ? Insufficient information

Afghanistan Region

3

Variant Names: Timurid Mausoleum, Madrasa and Mausoleum of Gawhar Shad (Gawharshad, Gauhar Shad, Gowhar Shad)

Location: Herat, Afghanistan

Architect/Planner: Qavam al-Din Shirazi

Client: Gawhar Shad

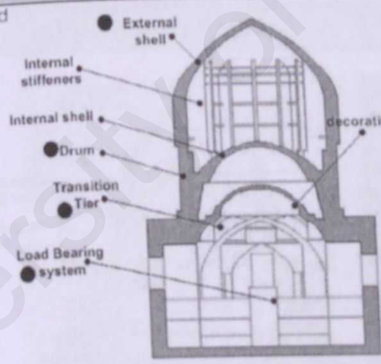
Date: 1417-1438 A.D.

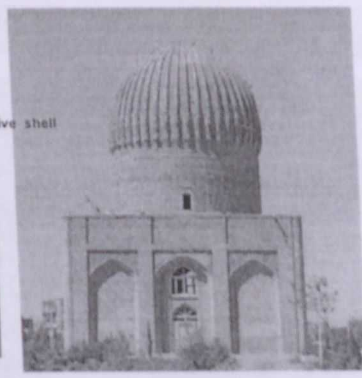
Style/Period: Timurid, Century 15th

Building Type: Educational, Funerary

Building Usage: Madrasa, Mausoleum

Dome Typology: Compound with drum





4

Variant Names: Ziarat-i Shahzade Abu'l Qasim, Mazar-e Abu'l Qasim, Shahzada Kasim Mausoleum ***Location:*** Herat, Afganistan

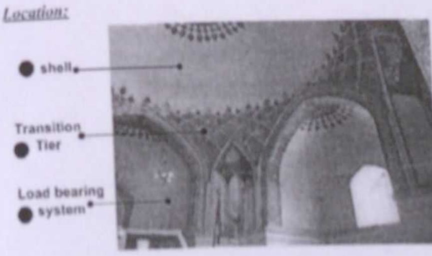
Date: 1492 A.D.

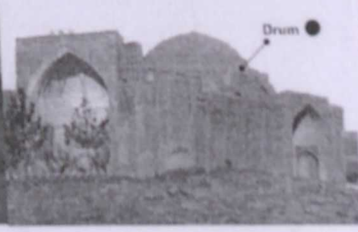
Style/Period: Timurid, 15th

Building Type: Funerary, Religious

Building Usage: Tomb, Madrasa

Dome Typology: Simple with drum





A Conical shell ? Insufficient information

Table B.3: Illustrations on case studies in zone III: Afghanistan and Pakistan regions (Continued).

Afghanistan Region

5

Variant Names: Mausoleum of Abu Mansur Nasir al-Din Sebuktigin

Location: Ghazni, Afghanistan

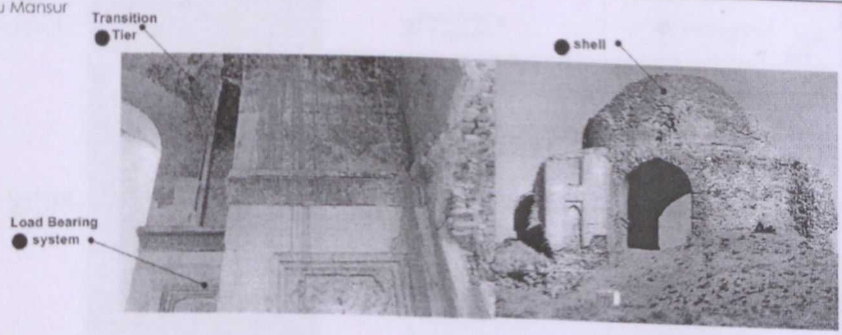
Date: 1417-1438 A.D.

Style/Period: Ghaznavid

Building Type: Funerary

Building Usage: Mausoleum

Dome Typology: Simple without drum



6

Variant Names: Hazrat 'Ali Shrine, Tomb and Shrine of Caliph 'Ali bin Abi Talib

Client: Sultan Husain Baiqara

Location: Mazar-e Sharif, Afganistan

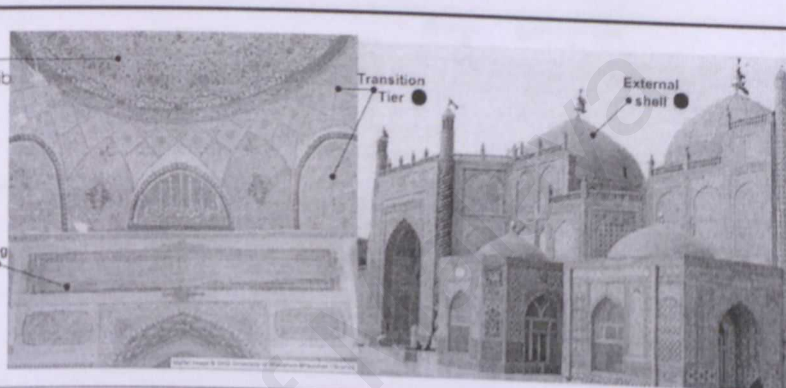
Date: 1480-1481 A.D.

Style/Period: Timurid, 15th

Building Type: Funerary, Religious

Building Usage: Mausoleum, Shrine

Dome Typology: Compound with drum



A Conical shell ? Insufficient information

Afghanistan Region

7

Variant Names: Maqbara-i-Timur Shah, Maqbara-i Timurshah, Timur Shah Tomb

Location: Kabul, Afghanistan

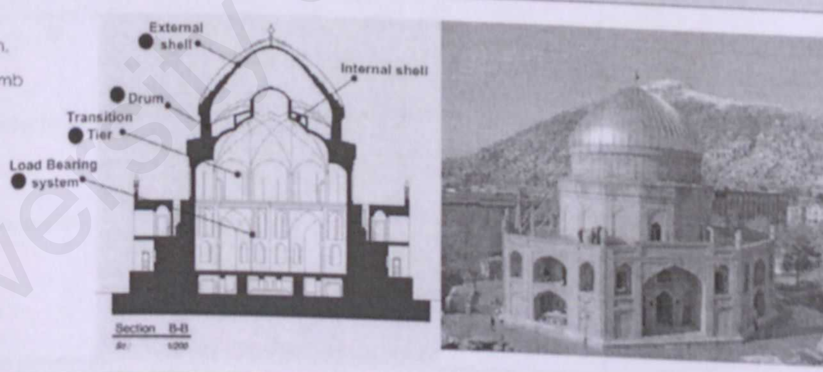
Date: 1793 A.D.

Style/Period: Abdali, Century 18th

Building Type: Funerary

Building Usage: Mausoleum

Dome Typology: Compound with drum



A Conical shell ? Insufficient information

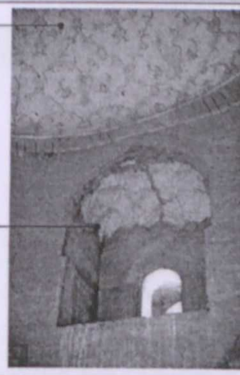
Table B.3: Illustrations on case studies in zone III: Afghanistan and Pakistan regions (Continued).

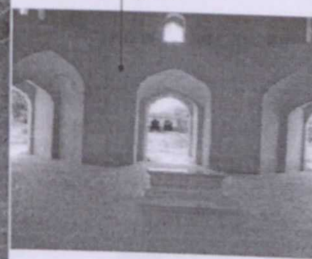
Pakistan Region

1

Variant Names: Asif Khan Tomb, Mirza Abdul Hasan Asif Jah
Location: Lahore, Pakistan
Client: Shah Jahan
Date: ca. 1641-5, Century 17th
Style/Period: Mughal, Century 17 th
Building Type: Funerary
Building Usage: Tomb

Dome Typology: Compound with drum

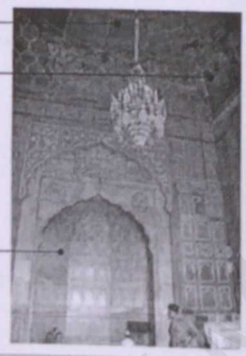


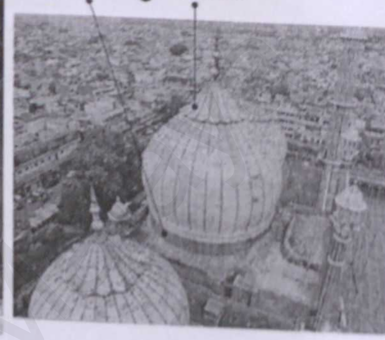


2

Variant Names: Part of site Lahore Fort Complex: Badshaahi Mosque ,Badshahi Mosque
Architect: Muhammad Wali Ullah Khan
Location: Lahore, Pakistan
Date: 1673-4, restored 1983 A.D.
Style/Period: Mughal, 17th Centuries 17th, 20th, Decade 1980s
Building Type: Religious
Building Usage: Mosque

Dome Typology: Compound with drum





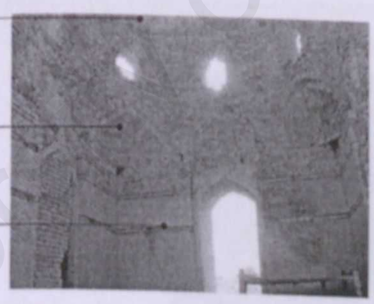
A Conical shell ? Insufficient information

Pakistan Region

3

Variant Names: Baha Ul-Haleem Tomb, Baha' al-Din Uchchhi, Qazi Baha' al Din, Baha' al-Halim
Location: Uch Sharif, Pakistan
Date: 1370 A.D.
Style/Period: Century 14 th
Building Type: Funerary
Building Usage: Tomb

Dome Typology: Simple without drum



4

Variant Names: Bibi Jawindi Tomb
Location: Uch Sharif, Pakistan
Date: 1494 A.D.
Style/Period: Timurid, Century 15th
Building Type: Funerary
Building Usage: Tomb

Dome Typology: Simple without drum

A Conical shell ? Insufficient information

Table B.3: Illustrations on case studies in zone III: Afghanistan and Pakistan regions (Continued).

Pakistan Region

5

Variant Names: Tomb of Shah Rukn-i Alam

Location: Multan, Pakistan

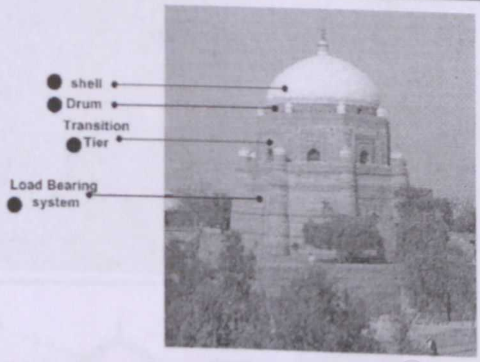
Date: ca. 1320-1324 A.D.

Style/Period: Century 14 th

Building Type: Funerary

Building Usage: Tomb

Dome Typology: Simple with drum



6

Variant Names: Sheikh Baha ul-Din Zakariya, Shaikh Bahauddin Zakarya Mausoleum, Hazrat Baha-ud-Din Zakaria Tomb, Saint Baha-al-Din Zakariyya Tomb

Location: Multan, Pakistan

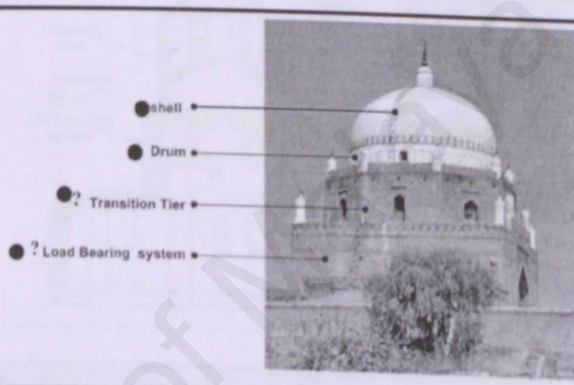
Date: 1262 A.D.

Style/Period: Century 13th

Building Type: Religious

Building Usage: Mosque

Dome Typology: Simple with drum



A Conical shell ? Insufficient information

Pakistan Region

7

Variant Names: Tomb of Sultan Ahmed Qatal

Location: Jalalpur Pirwala , Pakistan

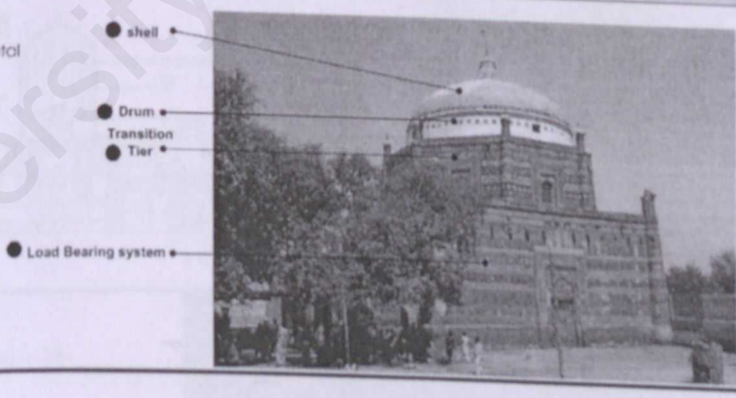
Date: 1821 A.D.

Style/Period: Century 19 th

Building Type: Funerary

Building Usage: Tomb

Dome Typology: Simple with drum



A Conical shell ? Insufficient information

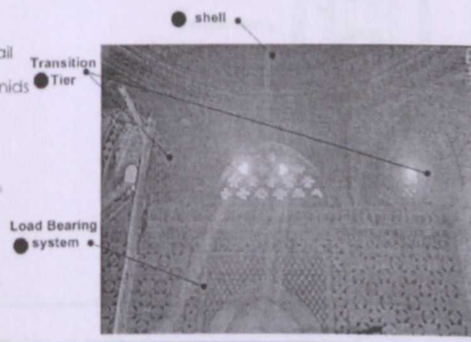
Table B.4: Illustrations on case studies in zone IV: Uzbekistan, Kazakhstan, and Turkmenistan regions.

Uzbekistan Region

1

Variant Names: Mausoleum of Ismail Smanid, Mausoleum of the Samanids
Location: Bukhara, Uzbekistan
Date: ca. 914-943 A.D.
Style/Period: Samanid, Century 10^{th}
Building Type: Funerary
Building Usage: Mausoleum

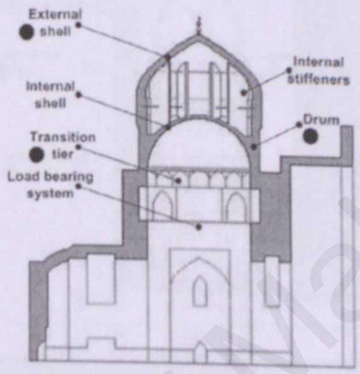
Dome Typology: Simple without drum



2

Variant Names: Kalyan Masjid, Masjid-I Jami, Congregational Mosque, Friday Mosque, Poi Kalyan Mosque, Poi Kalan Mosque
Location: Bukhara, Uzbekistan
Date: early 14th C., 1514 A.D.
Style/Period: Timurid, Shaybanid, Centuries 15^{th}, 16^{th}
Building Type: Religious
Building Usage: Mosque

Dome Typology: Compound with drum



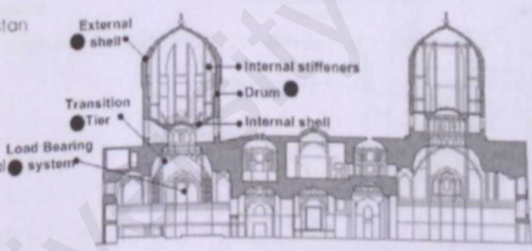
A Conical shell ? Insufficient information

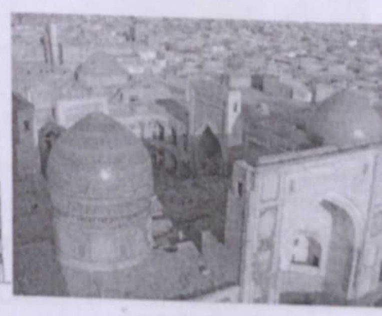
Uzbekistan Region

3

Variant Names: Mir Arab Madrasa, Mir-i-Arab Madrasa
Location: Bukhara, Uzbekistan
Date: 1417-1438 A.D.
Style/Period: Shaybanid, century 17^{th}
Building Type: Educational
Building Usage: Madrasa

Dome Typology: Compound with drum

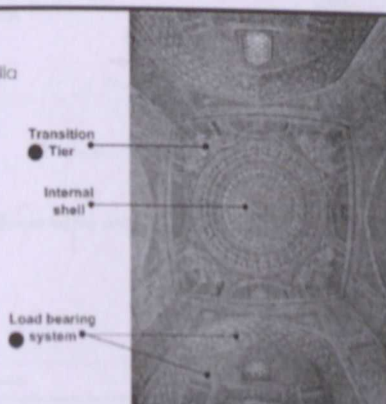


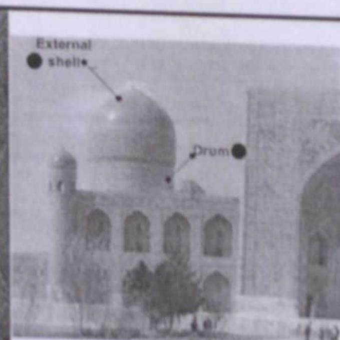


4

Variant Names: Tilla Kari Madrasa and Mosque, Tilla Kare Madrasa.
Client: Yalangtush Bahadur
Location: Samarkand, Uzbekistan
Date: 1646-1660 A.D.
Style/Period: Shaybanid, 17^{th}
Building Type: Educational
Building Usage: Madrasa

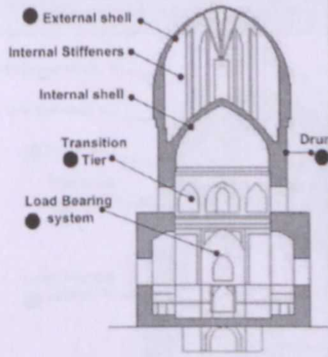
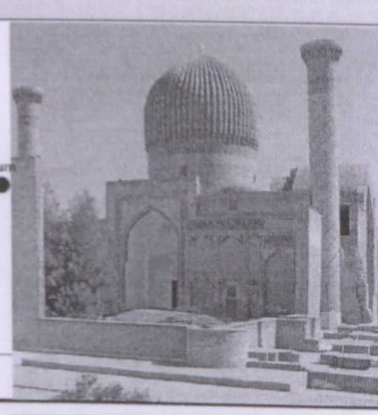
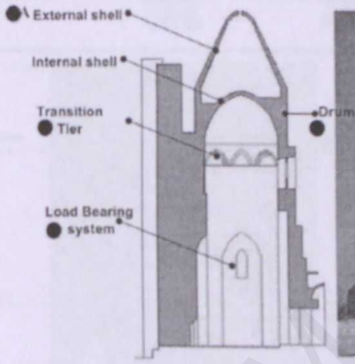
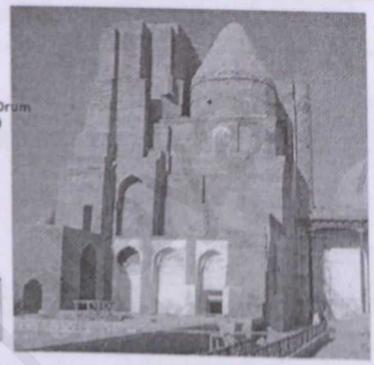
Dome Typology: Compound with drum



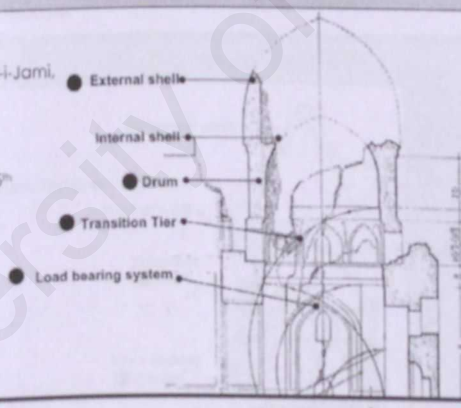
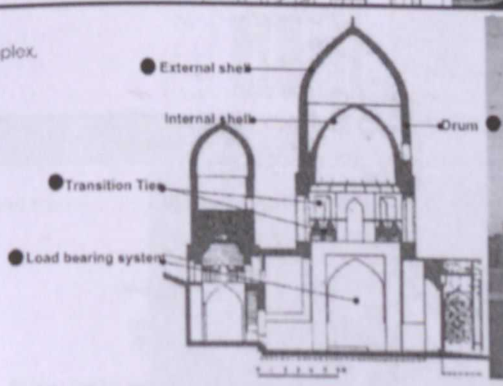


A Conical shell ? Insufficient information

Table B.4: Illustrations on case studies in zone IV: Uzbekistan, Kazakhstan, and Turkmenistan regions (Continued).

Uzbekistan Region		
5	***Variant Names:*** Mausoleum of Gur-e Amir Timur ***Location:*** Samarkand, Uzbekistan ***Date:*** 1404 A.D. ***Style/Period:*** Timurid, century 15^{th} ***Building Type:*** Funerary ***Building Usage:*** Mausoleum **Dome Typology: Compound with drum**	
6	***Variant Names:*** Mausoleum of Jahangir ***Location:*** shahrisabz, Uzbekistan ***Date:*** 1400 A.D. ***Style/Period:*** Timurids, century 15^{th} ***Building Type:*** Funerary ***Building Usage:*** Mausoleum **Dome Typology: Simple with drum**	

A Conical shell ? Insufficient information

Uzbekistan Region		
7	***Variant Names: ;*** Bibi Khanum Mosque,Masjid-i-Jami, Friday mosque of Timur ***Location:*** Samarkand, Uzbekistan ***Date:*** ***Style/Period:*** Timurid, Centuries, 14^{th}, 15^{th} ***Building Type:*** Religious ***Building Usage:*** Mousque **Dome Typology: Compound with drum**	
8	***Variant Names:*** Shah-i Zindeh mausoleum complex, Shah-i-Zinda mausoleums ***Location:*** Samarkand, Uzbekistan ***Date:*** 1000-1900 A.D. ***Style/Period:*** Samanid, Timurid, 11^{th}, 15^{th} ***Building Type:*** Funerary, Religious ***Building Usage:*** Mausoleum, Shrine **Dome Typology: Compound with drum**	

A Conical shell ? Insufficient information

Table B.4: Illustrations on case studies in zone IV: Uzbekistan, Kazakhstan, and Turkmenistan regions (Continued).

Turkmenistan Region

Variant Names: Mausoleum of Sultan Sanjar

Location: Merv, Turkmenistan

Date: 1157 A.D.

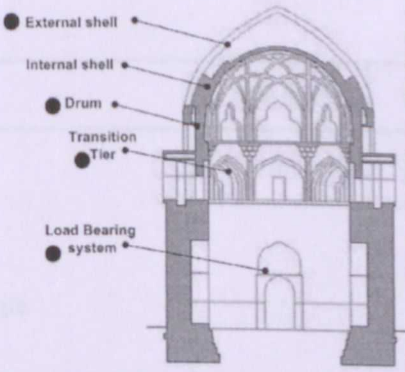
Style/Period: Seljuk, century 12th

Building Type: Funerary

Building Usage: Mausoleum

1

Dome Typology: Simple with drum



Variant Names: Shrine complex of Jamal al Din

Location: Anau, Turkmenistan

Date: 1455-6 A.D.

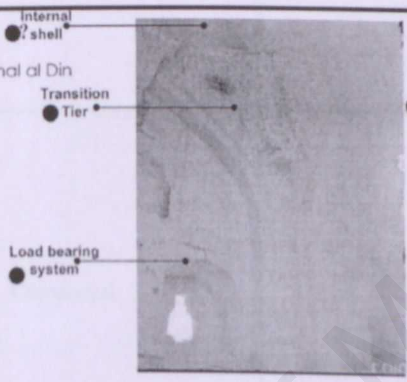
Style/Period: Timurid, 15th

Building Type: Funerary, Religious

Building Usage: Mausoleum, Shrine

2

Dome Typology: Compound with drum



A Conical shell ? Insufficient information

Turkmenistan Region

Variant Names: Turabek-Khanym Mausoleum, Tomb of Turabek Khanum

Location: Kunya Urgench, Turkmenistan

Date: ca. 770-1369 A.D.

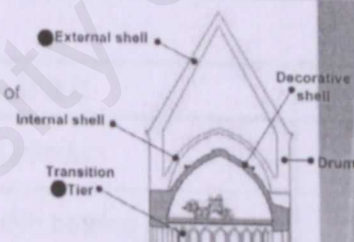
Style/Period: Seljuk, Timurid, 11th ,15th

Building Type: Funerary, Religious

Building Usage: Mausoleum, Shrine

3

Dome Typology: Simple with drum



Kazakhstan Region

Variant Names: Mausoleum of Khadja Ahmad Yasawi, Mausoleum of Sheikh Hodja Ahmed Yesivi

Location: Kazakhstan

Date: ca. 770-1369 A.D.

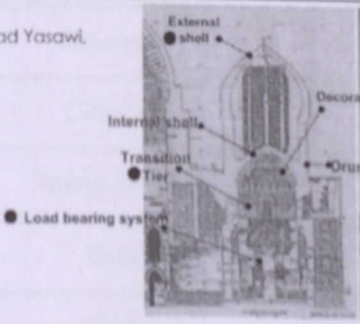
Style/Period: Timurid, 15th

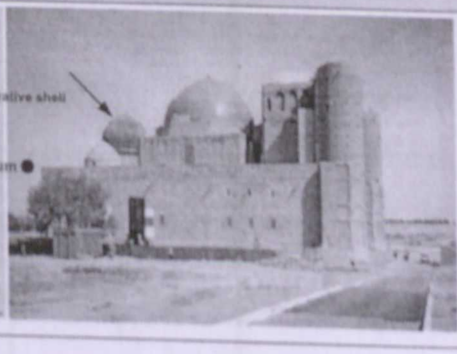
Building Type: Funerary

Building Usage: Mausoleum

1

Dome Typology: Compound with drum





A Conical shell ? Insufficient information

APPENDIX C

Tables including initial data derived from the four tables

ZoneI: Turkey		With drum	Without drum
Dome typology or generic form grammar	Simple	7	0
	Compound	4	0

ZoneIV: Iran & Iraq			Existing Numbers
Generic forms	Load bearing system	Cylindar	0
		Square with bearing wall	14
		Square with lateral vault	0
		Other	1
	Transition	Pendentive	0
		Squinch	17
	Drum	Circular	12
		Many-sided	3
	Shell	One	5
		Two	11
		Three	1

ZoneIV: Iran & Iraq		With drum	Without drum
Dome typology or generic form grammar	Simple	2	6
	Compound	8	0

ZoneIII: Afghanistan & Pakistan			Existing Numbers
Generic forms	Load bearing system	Cylindar	0
		Square with bearing wall	9
		Square with lateral vault	0
		Other	4
	Transition	Pendentive	0
		Squinch	13
	Drum	Circular	10
		Many-sided	0
	Shell	One	6
		Two	6
		Three	1

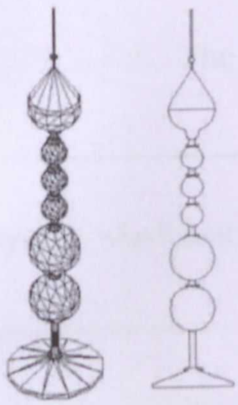
ZoneIII: Afghanistan & Pakistan		With drum	Without drum
Dome typology or generic form grammar	Simple	2	3
	Compound	8	0

ZoneIV: Uzbekistan & Turkmenistan			Exisitng Numbers
Generic forms	Load bearing system	Cylindar	0
		Square with bearing wall	10
		Square with lateral vault	1
		Other	0
	Transition	Pendentive	0
		Squinch	11
	Drum	Circular	10
		Many-sided	0
	Shell	One	1
		Two	9
		Three	1

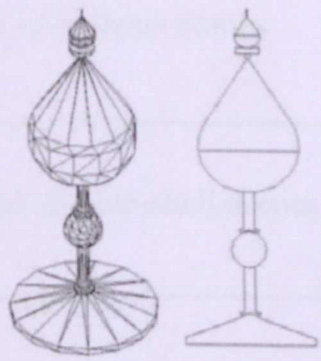
ZoneIV: Uzbekistan & Turkmenistan		With drum	Without drum
Dome typology or generic form grammar	Simple	1	1
	Compound	9	0

APPENDIX D

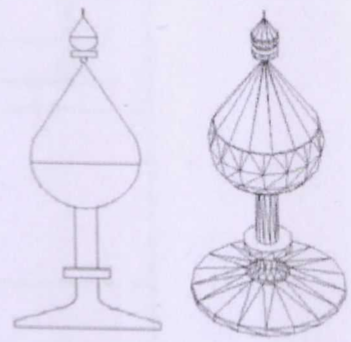
Various types of the derived metal protection of the studied samples



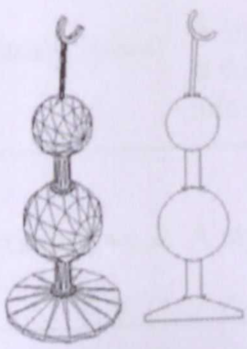
Case 7



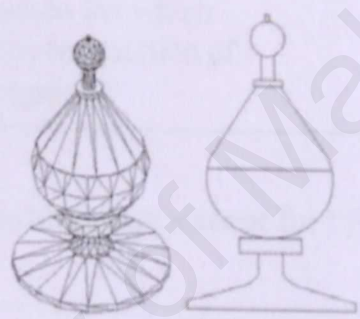
Case 8



Case 9



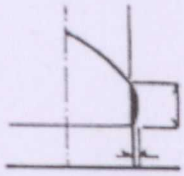
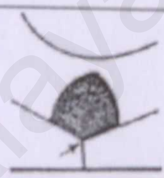
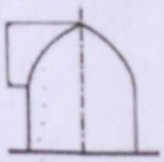
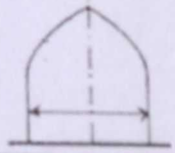
Case 10



Case 12

APPENDIX E

Some Persian local expressions of Dome Components

Avgun, آوگون:	The lower part of bulbous domes	
Ahlyana, آهیانه:	Internal shell of double-shell domes	
Khud, خود:	External shell	
Eskonj, اسکنج:	A type of transition tier which is constructed by intersection of mini-arches diagonally	
Toronba, ترنبه:	A style of transition tier, except for "Eskonj"	
Khashkhashi, خشخاشی:	Internal Stiffeners	
Afraz, افراز:	rise	
Dahana, دهانه:	span	
Horonu, هورنو:	oculus	