Journal of Regional History, Amritsar, Vol. XIII, 2013.
Sardar Mahan Singh Dhesi Annual Lecture 2012

INDO-ISLAMIC ARCHITECTURE: PROVENANCE & FORMATIVE INFLUENCES

Ravindra Kumar*

(Sardar Mahan Singh Dhesi, a pioneer Punjabi settler in California, spent almost half a century in the USA. He lived in California for more than half of his life from 1902 to 1945. The Annual Lecture has been instituted by Dr. Autar Singh Dhesi, grandson of Sardar Mahan Singh Dhesi and former Professor and Head, Punjab School of Economics, Guru Nanak Dev University, Amritsar (Punjab) India.

Sardar Mahan Singh Dhesi was the eledest son of Dewan Dhesi, 16th direct descendent of Chaus Dhesi who had about 3,500 acres of fertile land under his control in the Manjki area of Jalandhar district. Mahan Singh Dhesi's mother belonged to an aristocratic family of Jadali near Phagwara, associated with Maharaja Ranjit Singh, later bestowed with the title of Zaildar. Mahan Singh Dhesi was married to the eldest daughter of Bapu Waryam Singh, head man (Lambardar) *of village Virk, near Phagwara. Mahan Singh Dhesi's only son, Milkha Singh also inherited the title and property of Bapu Waryam Singh as his adopted son. Milkha Singh Dhesi's wife belonged to direct descendants' house of a princely state centered on Phagwara, covering vast tracts of present districts of Kapurthala, Jalandhar Nawanshehar, .and Hoshiarpur. One of the famous rulers of this state was Raja Hakumat Rai. Mahan Singh Dhesl ‘s only daughter, Kartar Kaur was married to the youngest son of Sardar Bahadur Sardar Chur Singh Zaildar of Cheema Khurd near Nurmahal. Chaus Dhesi had a number of illustrious descendents in the 17th and 18th centuries. The most renowned among them has been Baba Sang (Jodha) Dhesi, a revered Sikh Saint associated with Guru Arjan Dev. He preached universal brotherhood and Oneness of mankind. He was 9th direct descendent of Chaus Dhesi.*

Thus wrote Bhai Gurdas (Saint Paul of Sikhs) about Baba Ji:

Dhesi Jodh Husang Hai Gobind Gola Haas Milanda, *Vaar 11, Pauri 23.*

(Jodha Dhesi with Noble Face; His Devotee Interacts With Grace)

Bhai Sangtu Dhesi was a Commander (General) of Guru Hargobind's army. Bhai Bakat Dhesi, a writer in the Court of Guru Tegh Bahadur, was assigned the duty to record activities of young Guru Gobind Singh. Bhai Bakat Dhesi's grandson, General Nanu Singh Dhesi (10th descendent of Chaus Dhesi) was a distinguished army commander of Baba Banda Singh Bahadur who decisively defeated the army of ruler of (Sirhind) Fatehgarh Sahib.

With his rich heritage, Sardar Mahan Singh embodied the lofty civilizational values of altruism, charity and compassion for others. All along, he generously contributed to various activities initiated in California for social and educational uplift of rural Punjab. As an illustration of his compassion and concern for the welfare of fellow beings, Sardar Mahan Singh allowed surgeons to remove muscles from one of his legs to repair the limbs of a virtually crippled man from his village. He did this despite forewarnings of the surgeons that he might suffer circuiting pain- in his leg later, which he did for his remaining years. Yet, as a token of his magnanimity, he bequeathed a part of his estate to this co-villager. Earlier, he could not bear a young nephew of the beneficiary of his generosity and large heartedness being refused entry to the U.S. as young man's real uncle was not in the position to furnish the needed surety as per the then prevailing law. Later, he continued to assist the youngman to complete his study to become a dental surgeon who served in the U.S. Armed Forces during the World War II. One can go on enumerating such examples of his generosity and altruistic behavior. Editor)

*** Professor, Department of History, School of Social Sciences, Indira Gandhi National Open University, New Delhi**

Art and architecture are expressions of culture in a different media. The evolution of culture may be traced equally well in either of them and in manifestly visible forms. Perhaps architecture is a more concrete form of culture than even art. It is here that the ideas and techniques of a society find tangible, visual expression. The advent of the Turkish rule in India and via that the influence of Islam is significant in more than one respect. While it gave rise to a new socio-political system, it also marked the beginning of a new expression in art and architecture. The style of architecture that evolved during this time is called Indo-Islamic. In estimating the influence of Islam in the making of Indian civilization it is essential to understand the provenance of Indo-Islamic architecture and through this genre the formative influences which moulded Indian civilization and shaped its aesthetic needs and values.

In Islamic architecture the focus is on the enclosed space, as opposed to the outside. The most common expression of this attitude is the Muslim house. It is organized around an inner courtyard presenting to the outside world high windowless walls interrupted only by a low single door. Rarely does a facade give any indication of the inner organization or purpose of the building in question, and it is rare that an Islamic building can be understood, or even its principal features identified, by its exterior. The other more prominent feature is the distinction between urban & non-urban Islamic architecture. It is necessary to make a distinction between urban and non-urban Islamic architecture, because slightly different rules apply to these two different architectural expressions. Much Islamic architecture appears within the urban setting, though it must be added that a number of building-types were especially developed for the non-urban context, even if they frequently appear within the city as well. Most obvious is the *caravanserai*, which, in the majority of cases, appears in the open countryside along the principal travel routes. Next are the monumental tombs, which, almost without exception appear as isolated monuments, whether in an urban situation or within a proper cemetery. This is especially true when the monument commemorates an important personage; its very function as a commemorative structure makes 'visibility' and physical isolation imperative.

Other building-types that stand alone because of their specific function include fortified frontier structures (*ribats* & *qasrs),* hunting lodges and utilitarian structures, such as bridges, watch-towers, gateways and fortifications, especially those of the major cities themselves. Even though most of the building types appear as isolated visible structures with clearly defined and undistinguished exteriors, few breaks the rule, that is, are developed into architectural forms that can be fully comprehended from the exterior.

Two conclusions are obvious: first, very few building-types in the Muslim world articulate the interior space on their exteriors; and second, that these buildings are either, totally functional - bridges, watch-towers etc. – or true exceptions to the rule. In the case of the tomb or, for that matter, the mausoleum, we are in the presence of exceptional monuments that intrinsically demand to be clearly visible and free-standing.

Closely related to the concept of a 'hidden architecture' is the striking and almost total absence of a specific architectural form for a specific function. There are very few forms in Islamic architecture that cannot be adapted for a variety of purposes; conversely a Muslim building serving a specific function can assume a variety of forms. The paramount example of this phenomenon is the four – *iwan* structure of Central Asia and Iran, which is also found in other parts of the Muslim world. These structures function equally well as palace, mosque, *madrasa*, *caravanserai*, or private dwelling; at different times and in different places, in fact, they were built to serve all of these functions. In other words, an Islamic building does not automatically reveal, by its form, the function it serves. It need not be designed to serve a particular purpose, but is, in most cases, an abstract and 'perfect' scheme that can be used for a great variety of functions without any difficulties. Generally, Islamic architecture is given to hiding its principal features behind an unrevealing exterior; it is an architecture that does not change its forms easily, if at all, according to functional demands, but rather tends to adapt functions to preconceived forms which are basically the contained internal spaces.

With the exception of the tomb, the mausoleum and other similar domed structure, Islamic buildings rarely display an inherent directional or axial quality. On the contrary, the actual physical direction of a building, if it has any at all, is often different from its functional direction (which represents a total contradiction of the logical sense of direction expressed in European architecture). It is an ancient pre-Islamic concept, which appears to have survived, unaltered, into the architecture of the Islamic culture.

This lack of indication of a direction or focus in Islamic architectural design appears at all times and in all parts of the Muslim world; it is also clearly expressed in the lack of balance between the various parts of a building complex. Hindu architecture is generally designed as a complete balanced plan; Islamic architecture usually shows no such basic structure, and addition to an original plan are, consequently, never tampered by an inherent principle governing the whole and conditioning all parts in an equal manner. Enclosed space, defined by walls, arcades and vaults, is the most important element of Islamic architecture.

Decoration in Islamic architecture serves several functions, but its main effect – and very likely its main purpose – appears to be the creation of non-tectonic values, the dissolution of all those elements that in other architectural traditions emphasize the structure, the balance and counter-balance of loads and stresses – the actual mechanics of a building. Islamic architecture at its best, and at its most 'Islamic', is truly a negation of architecture, that is, of structure; it aims at a visual negation of the reality of weight and the necessity of support. The various means by which the effect of weight-less-ness is created, the effect of unlimited space, of non-substantiality of walls, pillars, and vaults are all well known.

I

The architecture in medieval India is marked by a widespread use of arch as the main structural form for spanning voids and the use of round dome as the main device to provide covering/roofing over walled spaces. It includes the introduction and large scale use of lime mortar as the foremost cementing material for joining individual structural elements – the stone blocks and the bricks – used in raising arches and domes. It also holds that the application of lime mortar was better suited for rough and porous surfaces of bricks which also provided smaller surface areas for the cementing properties of the mortar to act more efficiently. The constructions in brick therefore began to match constructions in stone at least numerically, if not in size, and the urban landscape of medieval India began to change gradually. It is contended that this "new" architectural device — arch made of bricks held in place by lime-mortar — was an advance over earlier methods and had even made masonry construction "affordable" proposition, yet had not completely supplanted the earlier column-and-beam structures. Instead the two allied and gave rise to a style generally identified as the Indo-Islamic architecture. That this style contains two different structural forms, is often cited as an attribute, though it should also be admitted that sometimes this combination is treated as bordering on the grotesque and having incongruous structural elements.

A study of the architecture would therefore chiefly concern itself with a probe into the design and structural behaviour of the forms and devices that were used in the buildings and other structures. It would thus examine the "new" form/s and the structural actions that come into play as they are actually used in the buildings, their inherent potentialities, the ways in which they facilitated construction, the manner in which they allied with the structural form/s practiced in the earlier period and the overriding considerations, if any, of the available building material, and the considerations of the "economy" of time consumed in completing the construction. The actual subsequent exploitation of this architectural technology in built structures based on the "wide range of choice" made available to the builders shall also be an area of our interest. In other words the essential purpose of this presentation is to highlight the provenance of and formative influences on Indo-Islamic Architecture. I am carefully avoiding the use of technical language though at times the structural analysis of forms etc. will require the use of some technical terms. An important point for us to note is that in most built structures the elemental structural forms (e.g. arch, column-and-beam etc.) have grown as essential parts of a larger building and not developed in isolation. The structural actions are therefore more complex sometimes than the simple understanding about them presented here. The historical period delineated here is from the establishment and consolidation of the rule of Turkish Sultans over Delhi in twelfth-thirteenth centuries to the decline of the Mughal Empire in the eighteenth century; the discussion though has sometimes followed a non-chronological approach so as to enable us to focus on structurally significant specimens across periods.

It is an interesting fact that generally structural forms have not been conceived in isolation and have imbibed influences from the past. The technical resources for an understanding of the structural actions were more limited in the past than they are today. Therefore actions of the earlier forms would mostly become legible to the architects through experience than through abstract principles of design. The process of development of these forms and the constraints surrounding this development was then based on their successes and failures over a period of time. Our discussion based on present-day understanding of the structural action should therefore be viewed with care in arriving at any qualitative judgment about their technical suitability at specific periods of time in history.

The principal structural form in use in India at the time of Turkish invasion was "column-and-beam" in which logs of timber or beams of stone were placed horizontally between two vertical columnar supports. The space so spanned formed part of a roof or an entrance in a wall. In making a roof, in fact, number of horizontal elements was set at a short distance apart and the in-between space was covered with slates, reed or such other material. The columns were also carved out of timber or stone or made of bricks. Alongside column-and-beam we also notice the early use of "false" arches and vaults with stepped soffits as another device to span openings or cover roofs. A characteristic feature of this form is that all the structural blocks (usually of stone or bricks) remain embedded horizontally on one another. As they rise to bridge the opening or to roof the enclosure they project slightly beyond those of the course below. Thus the gap to be spanned is narrowed progressively and eventually at the centre either the two sides meet or they approach near enough to be finally spanned by a single block.

The beam and column have been the simplest of all elemental forms but their primary structural actions – internal tensions and compressions – are perhaps the most complex ones to be subjected to an analysis. In order to understand the structural behaviour of different forms a brief analysis of the forces working on a structure will be of help. It will give us leads into learning the primary functions served by different structural forms in a building and the manner in which the stability of the buildings is served by architectural technologies employing these forms.

It is an axiom to say that the basic requirement in all architecture is that the structure remains standing and intact and does not collapse even under conditions of its use at some deviation from the "normal". While local deformations may occasionally take place, the main objective in choosing the structural form is that they (the deformations) are kept within acceptable limits and they do not in general jeopardize the stability of the structure. For this overall stability there are some basic imperatives: "active loads" should be balanced against resistances, the foundations should be able to bear the loads passed on by the structure, and sufficient margins of strength and stiffness should be available in the structural elements used for construction.

Let us understand these imperatives and associated features a little more closely. In a structure there are several types of load that become operative once the structure is completed. The gravitational self-weight of the structural elements and such other material used in the construction is foremost. In addition there are external pressures exerted by the users and by the environment on the structure. The user pressure is accounted for the people and the articles and material kept or carried through the structure. The pressure of the wind, heat or the impact of the coldness, and natural calamities as earthquake and lightening etc. constitute the environmental action on the structure. The self-weight of the structural elements is called the dead load; it does not change under normal circumstances and is determined by the nature of building material. The external pressure is called the live load; the magnitude of this load is not fixed and is determined by the regularity and frequency of use of the structure as also by the manner of its construction. In addition we have the reactive loads which become operative at the points where the structure is supported and where it terminates. Generally the reactive loads offset the force exerted by the dead and live loads, and depend on the manner in which the structure is terminated either at plinth level or at or below the foundations. The points of junction of different structural elements too show reactive loads.

The forces or loads discussed here, namely the dead and live loads– collectively called the active loads– and the reactive loads, have a normal tendency/proclivity to generate displacement in the direction in which they work. As a result a miniscule movement or displacement occurs; this gives rise to a resistance in the structure that attempts to defy the displacement. The structure remains intact under the forces so generated due largely to the fact that they are balanced by each other. The strength or stability of a structure is its ability to attain balance without too much displacement or deformity. It is also important to understand that these loads generally act quite slowly. This permits the development of resistance to keep pace, and the stability of the structure does not get endangered. Yet there may be situations in which there are swift changes in the loads causing resistance to not grow at the same pace, and bring deformities in the structure. The earthquakes emanating vibrations of great amplitude are illustrative instances of such actions.

It is thus clear that in choosing a configuration for a structure and in selecting the manner of its construction most of the subsequent forces operative on the structure are in a way pre-decided. While it is not possible to accurately predict the subsequent behaviour of a structure under the impact of loads likely to be borne by the structure, it is still possible to take care of some general structural requirements at the time of making the choices as above. These requirements are in addition to the selection made with respect to the structural form/s and the building material/s. In the first place is the requirement to organize the assembly of structural elements and their joints in such manner that the structure becomes a stable order and not an assemblage of loosely joined and disarrayed elements. Next is the requirement of having structural elements and their joints of such characteristics as to provide requisite strength. It is true that in complex structures i.e. having multiple components, it is not easy to discern these requirements and meet them for individual elements. It is more practical to account for the balances of forces at work in the structure at various points or to achieve, what in the technical term is called, a static equilibrium of the forces at work in the structure.

Now, to get back to the column-and-beam constructions, it is generally understood that the beams do not exert any appreciable horizontal force and the sizeable actions are only along vertical lines. In fact the dead load of the beam gets distributed over its length unlike a few other structural forms, such as arches and catenaries, where the dead load gets resolved into two resultants and operates at the points at which the arches and catenaries are supported. In general terms it can be said that the beams supported on vertical pillars or columns work as an “arch” and a “catenary” simultaneously. In other words, the two structural forms where loading actions operate conversely become combined in the beam; the resultant has a propensity to neutralize these converse loading actions. However, it is not easy to even approximate the axes or lines through which these actions or forces operate. We only know that normally the two forms remain in a state of equilibrium and it is only under the impact of any changed load on the beam that a readjustment in the two forms takes place. The beam gives way when this readjustment reaches its limit and fails. Either the "arch" or the "catenary" is disrupted and the collapse of the beam occurs.

The column-and-beam architecture was practiced in India from a very early time and this long experience had taught architects and builders many practical lessons. The structures were built in all the three principal materials viz. timber, stone, and brick but the strength and easy availability of stone had over time resulted in a preponderance of stone structures. Generally it was a combination of all the building material in which one predominated and the other materials used for other specific purposes. The strength of this architecture lay in its simple methods of construction and the abundance of building materials. It is true that stone was not a very friendly medium for visually embellishing the surface. But the Indian artisan had mastered the sculptural techniques to an immaculate perfection. The surface in these stone buildings as also in the other structural media was adorned with iconic figures of marvelous beauty. There were hardly any areas that were left undressed. However, the column-and-beam architecture suffered from at least one major structural shortcoming. The stone (or even timber) beam used for spanning purposes had only limited strength. Moreover, there was a maximum length in which it could be naturally procured. As a result there did operate a limitation on the span that could be covered by the stone beam and attempts to further increase the span would require additional columnar support. Not only ingenious expedients were available to override this deficiency; the architecture based on this technology was massive but composed of covered spaces that were long and narrow and where the columns were closely spaced.

The temple had come to typify the architectural form using column-and-beam device. Temple structures had sprung up in many variants in different parts of India since the time of the Gupta rulers. Beginning with flat-roofed simple structures having a pillared pavilion in front of the door-frame, the temple structures of the later periods came to signify one of the most elaborate and embellished constructions in pre-Turkish India. Many experiments with their plans and designs and equally expansive extensions in front of the architrave housing the deity resulted in the emergence of large rectangular stone (and occasionally brick) buildings that were also great visual delights. On the basis of their styles, Indian temples have been classified into three categories – Nagara, Dravida and Vesara. It is not our purpose here to delve deep into the architecture of temples. The intention is to stress the fact that quite diversified attributes of the temples were achieved with the use of column-and-beam device. High pyramidal superstructures marked by the Shikhar and profusely decorated outer surface having iconic representations from all hues of social and religious life became the distinguishing features of temple architecture. Thus when Turks came to India they encountered temple as the principal architectural form and column-and-beam as the main structural form practiced by the builders here.

The advent of the medieval period in India also marks the beginning of a new expression in architecture. New structural forms are introduced and the new forms – arch and vault/dome – are employed in architectural construction in many innovative ways. Arch and vault/dome are such versatile structural forms that they present numerous exciting possibilities to the architects. It will therefore be worth our while to seek to comprehend their structural characteristics and the actual mechanics of their usage, to truly appreciate their application in medieval Indian architecture.

The arch is usually a curved form and is normally made of wedge-shaped component blocks (in stone, brick or even concrete) fixed together firmly either by neatly dressing the adjoining surfaces of component with blocks for a tight joint with the help of a cementing material. The figure given here shows the typical features of an arch and its component parts. The curved form endows the arch with very special structural characteristics. Geometrically the arch is an unstable form prone to cracking or collapsing at one or more points along its curvature. The same curved form, nevertheless, attains stability and acquires remarkable properties of carrying loads of its component blocks (voussoirs, to be technically accurate) which are rigidly joined so as to form a continuous masonry. It is important for an arch to retain its curved shape to be able to retain all the remarkable properties. It is equally important for this curved formation to support itself at the two end points of the curve on firm bases. Once these essential conditions are met the arch achieves an equilibrium in which the dead load of the arch gets resolved into two parts each exerting a thrust at the point of support. This thrust operates through the line of tangent drawn along the curve on both sides. Since the end points are firmly rooted on the supports, the thrust gets resolved at this point into two components, the vertical downward thrust and the horizontal outward thrust. The vertical thrusts are generally transmitted through the supports to the foundations and only horizontal thrusts try to destabilize the arch. The net effect of all these forces is that the destabilizing action is generated by only a part of the total dead load while the remaining dead load is absorbed by the foundations. If the arch is burdened with active loads, by the same principle, only a part of it and not the whole would try to destabilize the arch. The practical aspects of this principle were of great value to the architects. It may have resolved their difficulty in not being able to increase the dead load beyond a certain limit, as was the case in the column-and-beam structures. Moreover larger spans could now be covered by arches without the necessity of any intermediate support.

The architectural use of the arch was first attempted by the Egyptians. Mud-brick arches dating back to a period early in the third millennium BC have been reported from Reqaqnah in Egypt. They were perhaps of the window arch type and were made of only a few bricks. Arch was, however, not preferred by ancient Egyptians as a structural form and the reasons for this were perhaps similar to the arch not finding a favour with the architects in ancient India. It was much later that adoption of arches began in the larger structures. In seventh century BC, we find brick archways of fairly wide span surviving in Thebes in middle Egypt. The use of stone in making arches began in Greece and Italy and later in Rome around fourth century BC. These arches were semi-circular in form and were made of stone voussoirs of such workmanship that they fitted quite closely in the semi-circular profile. In these arches there was no use of mortar. It seems the semi-circular shape was preferred so that these finely worked voussoirs would remain intact even without mortar. Great advance in using arch was made by the Romans. They refined the technique and introduced some very useful modifications in the shape. The design and construction of Roman arches also have a bearing, if indirect, on the kind of technology used in making arches in India during the medieval period.

The making of Roman arches involved the construction of support walls or columns up to the point from where the arch would spring up. At this level a false-work was raised having the same semi-circular shape as was desired for the arches. This was perhaps a cumbersome process and needed the support of carpenters who would create the false work (centering) in wood. It is of interest for us to note that semi-circular people could be easily attained only in wood and not in other materials. The next stage in construction was to accurately fix the voussoirs in place from both ends. As has been noted above, the craft of chiseling stone voussoirs was perfected by the Romans to such an extent that the two adjacent voussoirs joined together without leaving any crevice in between. This type of tight-fit was an absolutely necessity for the principle of load transfer on the supports to come in operation. As the crown was reached the key stone was tightly fitted in the available space. The keystone was a critical element that was to keep the semi-circular profile in place and was to bring the tangential thrusts of the two halves of the semi-circle to become operational at the points of support or the springing of the arch. Once this stage of construction was over the false work or centering was removed leaving the arch standing in place. Structural characteristics of Roman arches that emerge from this detail are of interest: the semi-circular arches were not capable of accommodating even the slightest movements of its supports, otherwise they would collapse; the curvature of the soffits had to be truly semi-circular that is no horizontal profile at any point was admissible otherwise the voussoirs would slip on each other causing their fall; the Romans used joggled voussoirs as an expedient to minimize the likelihood of slipping and also found it useful in situations where false work was not very firm and required an additional contrivance to keep the voussoirs in place at the time of construction. A few more innovations made by Romans are also noteworthy. From about the middle of the first century AD brick-faced concrete arches came into use. An interesting feature of these concrete arches was that they were penetrated by full bricks at regular distance. Perhaps the attempt was to create voussoir-like sections as component blocks of the arch. In technical terms though the concrete would have behaved in much the same fashion as the concrete structures of today would – as a complete monolithic curved formation. Towards the later part of the Roman empire along with semi-circular profile of the arches segmental profile was also introduced. It seems that in this process only slight departures from semi-circle were initially done. These departures were more a consequence of errors of construction than any deliberate attempts to experiment with a new profile. Subsequently arches with markedly segmental profile were used in their structures though in an irregular manner.

The departures from the simple semi-circular profile have been of seminal value in the development of arch as a structural form. The departures, as we have noted above, came about initially from the slight structural errors during the construction stage. But once the benefits of these "errors" became evident the departures became deliberate. Lessons were perhaps drawn from the observation that profiles at deviance from semi-circle were also quite strong. It would have been hard to anticipate the actual behaviour of the "departed" profiles but practical observations and strength and longevity would have assured the architects about their utility. The most significant new profile was the pointed arch. It offered advantages in construction that were impossible to ignore. These were: easy setting out of the arch; possibilities of using lighter centering than was required for a semi-circular or segmental arch; and the propensity to adjust its profile marginally to offset minor settlements due to poor foundations. The pointed arches appeared first in the Islamic world in Jordan in the eighth century AD and soon became one of the main features of the Islamic architecture of the region. Popularity of pointed arches speaks for the advantages they offered in case of construction. The regions of its early spread were wide deserts and jagged rocky uplands that were barren of wood or vegetation. The architects were therefore deprived of the advantage of creating centering made of timber unlike the Roman practice. Under these circumstances pointed arches were the most suitable proposition since they did not require an all-timber centering in their construction. In fact material other than timber which could be locally procured was used in centering. This material was brick and a combination of timber with brick or sometimes bricks alone were used in making the centering. The bottom layer of light centering was constructed first and then a thin layer of bricks was placed on it. If needed, another concentric layer of brickwork was also added over it and the arch was to be raised over these layers of bricks. Often these two layers of brickwork acted as permanent shuttering for the arch. Since pointed arch would impose less load on the centering and a smaller horizontal thrust at the support than semi-circular profile the method described thus worked quite efficiently. The horizontal thrust in the pointed profile was minimized because the rise in pointed arches was greater than the span. The line of thrust at the support would therefore resolve into horizontal and vertical thrusts such that the vertical thrust increased and the horizontal thrust got reduced in the same proportion. This arch was therefore found better equipped than the semi-circular arch in dealing with conditions were stable foundations were difficult to obtain and where timber was not easily available for raising the false work.

It would appear, at first sight, from the account given above that for the architects it was rational choice to opt for the pointed arch. The architect's freedom to choose its form when a structure is to be constructed, however, is a complex process in which many inter-connected factors come into play. In addition to the basic structural requirements of the building and the availability of the material the architects have to contend with the application of particular techniques of construction within the available mechanical aids and human skills. It has often been found that the architects have developed ingenious methods to cope with such situations and suitable adjustments in the structural form/s have been made to overcome constraints at least partially if not completely. The introduction of arch – the pointed arch in medieval India - presents a somewhat similar situation. The architects employed by the new rulers – early Turkish Sultans – were given the task of assembling a built form that would in shape be a pointed arch. The assurance gained in their homeland about the strength of pointed arch was now to be translated into practice in "alien" conditions. The architects had also to tackle with the problem of securing adequate stability and strength to the arch at intermediate stages of construction. The availability of building material and its fabrication into desired shape, and the methods of joining them together were also issues seeking a resolution. The first buildings were raised under such conditions.

The first structure raised by the new rulers was the mosque in the Qutb Minar area at Delhi popularly known as the Quwwatul Islam mosque which was completed in 1195 AD. It was built on the ruins of a temple by integrating its plinth within the plinth of the mosque. The material for the mosque was not fabricated afresh but the material (stone) used in twenty-seven other temples of the area and demolished by Qutbuddin was largely reorganized to serve the purpose. It is a well known fact that at such an early stage of their rule the Sultans were ill-equipped to use an architectural technology very different from the one already practiced in India. The mosque - its prayer hall and the colonnade – was built by using the column-and-beam device. Pillars-sculpted ones- from the demolished temples were reused as columns and beams and were put in place with the help of brackets to complete the colonnade. The craft of the mason in assembling the mosque from the spoils collected from the temples is remarkable. Obviously the principal consideration was architectural exigency as aesthetics had perforce to take a back seat. The columns, brackets, and lintels were reused without being reworked in any significant manner and the mosque was completed. The covered colonnade all around the central courtyard was also provided with shallow domes at periodic intervals. These were "false" domes built by laying successive courses of horizontal stones where each upper layer was projected slightly inward. As the top of the dome was reached the space was gradually narrowed. Finally a round stone at the top completed the form.

The mosque was begun in 1191-92 A.D. and completed by 1195. It was a completely column-and-beam structure with no use of arch whether "false" or true. The first notable change in the structural form was effected four years later in 1199 when a screen was added in front of the prayer hall. It was in this screen that arches were introduced though they were of the "false" order - not having stones arranged in the form of true voussoirs. A detailed analysis of this early arch form is of great utility in gaining an insight into the processes and methods at work in the erstwhile architectural technology. We have noted earlier that the process of construction during the early phase of Sultanate architecture operated within certain constrains – having to work with skills and aids not of the desired competence and the availability of only a particular type of building material, the spoils of the temples chiefly. It is evident that these "false" arches were chosen so that the requirement of raising any temporary support during the different pre-completion stages of construction would not arise and as described earlier the two halves of the arch would be raised as stable halves independent of each other. It is logical to assume that in this kind of over- sailing elements architects would have learnt that it was always necessary to keep length of the projections in the upper course small, but under no circumstances to exceed half of its length. Similarly the total weight of the stone elements, or for that matter the other masonry used in making each half of the arch, was also to be distributed such that the weight behind the project would be more – much more – than the weight of the projection itself. If shorter blocks of stones were used in the arch, and not monolithic blocks, the force acting on each individual unit was frictional force at the two horizontal joints, below and above. There would practically be no vertical resistance. The possibilities of any deformity in this arch would arise as a result of "weak" or insufficient horizontal friction at joints leading to slipping, tipping etc. Such an arch was therefore stable generally for moderate spans. When the span was to be increased it was necessary to use sufficiently long stone blocks and it was equally necessary to anchor them properly to the mass of the support wall on either side.

The shape of the "false" arches built in the screen was pointed ogee having a slight curve at the crown. It is evident that in raising these arches centering was not needed. But it is equally true that due to the technical limitations the scope of widening the span would also be very limited. The screen built by Qutbuddin was subject to two extensions subsequently, one by Iltutmish and the other by Alauddin Khalji. Both the extensions today retain only the jambs or walls on which the ("false") arches were raised but the arches do not survive. Since the two extensions were also bigger in proportion, it is most likely that aches failed either the test of horizontal friction or of the anchor. Noteworthy is the fact that the arches of smaller span in these extensions have survived and only the central wider arches have perished. Sufficient confidence to build structures having true arches was not gathered soon and the practice of using corbel and column-and-beam device was continued for a little over a century since the construction of Quwwatul Islam mosque. During this period no major changes were introduced in the methods of construction except perhaps a few experiments made with the shape of the arches. We note that the ogee form employed in the screen by Qutbuddin was altered when the first extension was carried out by Iltutmish. The ogee cusp was replaced with a simple pointed arch formation which, as noted by Percy Brown, was "not very dissimilar from the pointed arch of Decorated Gothic style appearing about the same time in England". In fact this form was closer to the four-centered arch of the Lodi and Mughal period; we can see this form in the central arch of the screen added by Iltutmish to *Arhai-Din-Ka- Jhompra* mosque originally built by Qutbuddin at Ajmer (begun in 1200 AD). A new form that makes an appearance in the Ajmer structure is the trefoil pointed arch, used in the two side arches on each flank. The two end arches of the seven-arched screen are again of the four-centered type.

After more than a hundred years of experimentation with corbel and column-and-beam methods, and the use of "false" arches, the next logical stage in the development of architectural technology was the construction of the true arch which appeared for the first time in Alai Darwaza, an entrance gateway built by Alauddin Khalji at the Qutb Complex in 1311 AD. Like Iltutmish, another extension of the Quwwatul Islam mosque was planned by Alauddin. The scheme was to double the size of the complex. Thus the structure originally built by Qutbuddin, and subsequently extended by Iltutmish, was meant to be expanded to more than four times its size. In the new lay-out four gateways were planned such that each was an elaborate complex on its own. Today only the southern gateway survives and is popularly known as Alai Darwaza. Perhaps this was the only one to have been completed as indicated from the sites and ruins of the proposed extension of the mosque under Alauddin. The gateway has four arched openings, one in each wall. The three, in east, west and south walls, are pointed ogee arches while the fourth one, in northern wall, is a semi-circular arch. As stated above the true arch (having structural elements arranged as voussoirs) appears in a medieval building in India for the first time in Alai Darwaza. Significantly, the semi-circular arch too makes a brief appearance here as it is not found used in other contemporary buildings and also vanishes almost completely from the buildings of the succeeding period.

All the arches in Alai Darwaza have been built of freshly fabricated stone unlike the usual earlier practice of reuse of the temple stones. (Fresh stones were, in any case, cut and dressed for the screen built by Qutbuddin and later extended by Iltutmish.) The three pointed arches have been built of stone slabs measuring approximately 2.75 meters in length. Interestingly these arches have been constructed of full length stone slabs; the practice of making several concentric rings of arches of smaller width has not been employed here. As a matter of fact the pointed arches in Alai Darwaza are built with such long voussoirs that they in effect constitute a vaulted passageway. It seems plausible that at such an early stage of constructing the arch the architects were not confident about their methods; hence the use of long voussoirs instead of smaller elements and the method of making several layers of concentric rings of arches. The span of these pointed arches is only a little more than 3.00 meters each. This is not a very wide span and understandably so at this (probably the) first use of true arch having voussoirs. There is no direct evidence available to give us information about the different stages of construction of these arches. We may, however, safely assume that they were built with the aid of centering – the fine finish of their joints and the thin, uniform thickness of the cementing material providing the testimony.

The northern entrance arch, as noted above, is a semi-circular arch. But its manner of construction indicates certain indecisiveness on the part of the architect. It seems, an attempt has been made to use the semi-circular form in the same material as was fabricated for the pointed arches. The keystone is therefore not as pronounced as it should normally have been in a semi-circular arch. The voussoirs have been arranged such that they appear as a combination of "horizontal" and "curved" soffits. The arch stands intact because the depth of its voussoirs is sufficient to resist the "slip" resulting from such construction. It is evident that some experimentation with the form of arches was definitely on at the time of building Alai Darwaza. The favour shown to the pointed arch in the other contemporary buildings and in the subsequent period too did not mean that attempts, even though sundry, were not made to use the other forms, particularly the semi-circular form. It may be interesting for us to know that the confidence gained with the use of pointed arch was soon translated into its application in more utilitarian structures such as in building bridges across rivulets and streams of not very long spans. A three-arched bridge stands extant across a seasonal stream in front of Siri, Alauddin's new capital at Delhi. Another larger bridge of eleven arches was built to provide passage across river Gambhir below Chittaurgarh fort. One of the arches of this bridge is a semi-circular arch while all the remaining ones are pointed arches of the same type as built in Alai Darwaza. It is of some interest for us to note that the column-and-beam method was not forsaken altogether in favour of the arcuate constructions; the extension proposed by Alauddin in the Quwwatul Islam mosque complex was undertaken by employing the column-and-beam device as is evident from a small surviving portion located in its south-east corner.

The wider application of arch, made possible from the successful experiment of the Khalji period, also brought into focus the question of achieving an overall stability of the building in addition to the durability and load-bearing properties of individual structural elements. It was important to ensure that individual structural elements in a completed building were not so arranged that the collapse of one would jeopardize the entire structure. The column-and-beam buildings were more stable in this respect because structural elements acted almost completely in tension. Destabilizing forces of moderate intensity generated small displacements in these elements. As against this, the arches were the type of structural forms that acted in compression. Even small displacements in such cases had the tendency to inflict larger instabilities. Therefore, if the arches in a complete structure were so arranged as to be interlinked with each other structurally (such as in a long arcade), it was an added risk that the collapse of one arch was likely to result in the collapse of the entire building. It was then important to either structurally "de-link" arches or to introduce an additional element in the arch having a different pattern of loading action from that of the arch. Sometimes the addition of a beam to the arch was found an adequate device to address this issue. Tughlaq period buildings, where large scale use of arch was practiced and a new material – the rubble – was employed in major building projects, show the adoption of some new and interesting features. Foremost is the use of a pointed arch having a profile much closer to the profile of a four-centered arch? This was a significant change as it allowed two major advantages to the architects: the first was to give a leeway in extending the span of the arches without, in the same proportion, raising the height of the arches; and the second was to give an additional strength to the arch since it now worked as composed of four instead of two parts. We can even call this form a more "squat" arch than the pointed arch used hitherto. The other notable feature, also accepted as the brand-Tughlaq attribute, is the use of an "extra" beam or lintel invariably in association with the arch. The beam/lintel always appears at the base of the arch that is spread across the span of the arch at the springing point or at a point little lower than that. The addition of a beam in this manner has been mostly described as "technically irrational," not having any structural merit and as a mere ornamentation or a continuance of an old habit not easily forgotten. We have noted above that structures using several arches needed a composition in which the failure of one arch was not likely to endanger other arches and thereby the entire structure. The introduction of beam/lintel as different structural form was perhaps an expedient to guard against an interlinked structural dependence of multiple arches in a single structure. The large scale use of rubble would have reinforced the arch-beam arrangement. In fairness to the medieval architects, though, it must be said that it took them quite some time to realize that in practice no standing structure behaved as closely interlinked as to suffer a collapse due to the failure of one or more of its structural elements.

Before we move ahead it is necessary to comprehend the meaning and significance of the change in building material from the ashlars to stone rubble on a large scale under the Tughlaqs. The readily quarried sand stone, mostly with rough and random surfaces required a slightly different treatment. The architects were sure about the durability of this material - strength of stone as a structural element was time tested. Perhaps what they doubted was the strength of the structure built in rubble and the load bearing capacity of the forms created in rubble. We have noted above the "contrivance" employed in arch making – combining arch with an additional beam to seemingly provide added strength to rubble arches. The other structural device used conspicuously in Tughlaq buildings was the sloping effect in walls, columns etc. by unusually widening the base and reducing this width gradually upwards. A detailed comment made by Percy Brown, specifically for the structures of Firuz Tughlaq's period, holds equally good for the entire Tughlaq period: "The materials and method of construction employed by the Firuzian builders naturally reacted on the character of the architectural style. With masonry of this loosely knit order, additional strength and stability was assured by building certain portions thicker at the base than at the top, an expedient which gives the illusion of greater power, although no such angle of batter is really structurally necessary. This effect of slope is emphasized in many of the examples by the attachment of tapering turreted buttresses at the quoins, and by projecting conical bastion-like towers crowned with low domes from the four corners of the building." Evidently the strength of the structure made of rubble was uppermost in the minds of architects while resorting to the extra wide bases of walls and tapering them upwards.

A subject, we have not addressed so far but which can no longer be deferred relates to the medium in which the rubble was set, in other words the cementing material used in joining the rubble for raising the structure. It is quite clear that the requirement of cementing material or mortar in construction work based on rubble was much more than in the ashlars. Simultaneously the construction method used in raising the arch was also dependent on a good quality cementing material that would hold the voussoirs in place and would allow the loading actions in curved shape to operate tangentially as illustrated earlier. Therefore the development of arch as a structural form and its application in different situations in structures demanded the ready availability of a strong cementing mortar. This cementing material was lime mortar; the recognition of its adhesive properties and its early use in masonry construction is generally attributed to the Romans. It is said that the cementing action of lime was discovered "accidentally" when it was employed in the form of rubble fillings between the two faces of walls made of dressed stone and inside a square or rectangular dressed stone pier. The device was used to economize on construction in making walls and piers of extra thickness. With the passage of time, it was discovered, the casing walls had given way but the rubble fillings remained intact and exhibited appreciable strength. It seems the Romans soon found out the good cementing properties of p*ozzolana* (volcanic ash found near Rome) and also the more satisfactory manner of its application than a mortar using lime as the basic ingredient. The different cementing action of lime mortar and *pozzolanic* mortar has been clearly described by Mainstone (*Developments in Structural Form)*: "As lime mortar gains strength only by Carbonation of the lime as a result of contact with the atmosphere. It therefore does so very slowly in the centre of any large mass, and large proportions of the lime may remain unchanged even for thousands of years. A pozzolanic mortar contains a further active ingredient – a compound of silica or alumina – which reacts directly with the lime independently of the atmosphere. It hardens much more rapidly, attains higher strengths, and is much more durable in the presence of water." It is very significant that references to the use of lime mortar, independently of Roman discovery, have also come from India, and they date back to second century BC.

The use of lime mortar as a cementing material in the Islamic world had gained added importance in view of the fact that pointed arch had been adopted as a preferred form and this needed the stone or brick voussoirs to be cemented firmly to hold the pointed form in shape. As we have noted earlier, in the case of semi-circular arches (especially of the Romans) there was no such cementing requirement if the keystone was accurately fitted. There is some ambiguity about the precise nature of the main ingredient used in the mortar in the Islamic world. It is not clear whether 'gypsum' or 'lime' is meant in the records. Since gypsum was more easily prepared, it was a common bonding agent for mortar used in much of the Islamic World throughout the medieval period. There is some evidence, however, that mortar manufactured from lime wherever available, was preferred for the foundations and the corners of buildings. Gypsum mortar was then used for pointing the joints of face stonework or brickwork, in which case the mortar of the inner faces and cores of walls was seldom more than a local clay grout, occasionally mixed with chaff or straw. The use of lime mortar and/or gypsum mortar in medieval India has not been properly documented. One study that discusses the making of mortar relates to Mughal India. It is, however, not very unreasonable to assume that most of the inferences drawn there, if not all, would also hold for the Sultanate period.

The use of both lime – and gypsum – mortar in medieval India was widespread. Several kinds of lime were in use and the use of special types of mortar for specific parts of the building was also a common practice. Lime was obtained from three principal sources – Lime stone, gravel, and marine shells. The preparation of mortar had gradually developed into a specialized crafts. In the Mughal period the mortar was improved for its adhesive properties by mixing "a number of gelatinous, glutinous, resinous and non-resinous cementing agents". Much in the Roman manner of adding ingredients such as crushed under-fired brick, tile, or potsherds, in medieval India too lime mortar was mixed with "pounded bricks". There is also mention of the preparation and application of mortar for special purposes – for constructions that required water-leakage, e.g. indigo-vats, and for plastering on the walls of the structures.

It is important to note that the effective use of lime mortar was possible only on "small" and porous surfaces. If the joints were wide, the adhesive property of the mortar was not likely to generate adequate compressive strength that was so vital a factor for holding structural forms such as an arch or a dome intact. Therefore, use of bricks as building-material was found to be of greater utility in making arches and domes which used lime mortar as the main cementing agent.

Now, returning to the developments in arch we discover that the experimental four-centered arch of the Tughlaqs finally blossomed into a proper four-centered arch under Akbar. The curvature changed such that arch could now be divided into four segments each having a different centre of gravity. In architectural terms the great advantage derived from such a shape was that the architect could henceforth increase the span and yet will have only marginal increase in the height that is, the rise of the arch. It not only provided technical advantages but also introduced certain elegance in compositions employing this arch. In red sand stone, Akbar's favourite building material, this arch assumed a distinctly recognizable character.

One of the most distinguishing features of the architecture of the sixteenth century (especially the second half) was the combination of two different structural forms judiciously used for particular structural purposes. Arch was used principally in gateways and buildings needed for congregations of people for various purposes (e.g. *barahdari*, *diwan-i aam* etc.). Column-and-beam method was used for roofing, in colonnades and in entrances to chambers and also in other buildings. The objective clearly was to economize on construction that is to achieve greater output from the efforts put in composing the complete structures. The stability and the load-bearing capacity of the two forms had also been grasped. The parts of building where greater stresses were likely to occur were provided with arches; in those parts where load arranged for near vertical transference to the foundations, columns and beams were used in association with brackets and capitals of varying sizes. In fact brackets and capitals constitute significant element of architecture of this period.

The only other change in arch making came when marble was introduced as a building material on a wide scale in the seventeenth century. The curves of the arch were modified from the continuous line profile to a multi-foliated profile. Generally there were nine cusps in each arch, four in each half and one at the crown. Cusps were however, increased in places where the span of the arches were fairly big. The introduction of foliates is decorative in essence without altering the structural characteristics of the arch.

II

We shall now consider dome and its application in architecture. We should remember that dome is an important space-enclosing structural element, and the development of its structural form was associated with, prompted and stimulated by, even at times overshadowed by, many non-structural objectives and overtones. The development of dome was facilitated by the discovery and perfection of the arch – the dome is in fact an arch rotated around its principal axis. The development of dome, although facilitated by the arch was not a simultaneous process; early domes did not use arches as they were raised by using over sailing courses of circular or segmental stone beams. The true domes were late-comers and became popular only when dressing of stones in the required wedge-shape and the technique of placing the centering achieved a certain level of advancement. The early true domes survive from 2nd-1st century BC period and, interestingly, are structures made of Roman pozzolana concrete, not of stone or brick. Since the use of concrete required a good centering to be in place for domical construction, early domes did not directly take off from arch and had to wait until centering techniques were developed. The use of stone and brick in place of concrete was a still later development and it also involved a certain change in the construction method. The concrete domes required a good centering to be set up and several circumferential frames to be placed at different heights along the vertical rise of dome to hold the concrete in place until it dried and firmed up. Against this method, the brick or stone domes needed to be raised layer by layer of arches or several rings of arches. Here the free-flowing composition of concrete domes was not possible. The other technicality that needed a resolution related to the conversion of usually square base of walls in the enclosed space, from where the dome was to rise, to a circular base so that the hemispherical shape of the dome could be conveniently attained. In the making of a concrete dome this issue would not be so acute. The centering of the concrete dome would take care of transition by either placing cross beams at corners or beginning the centering itself from lower points at corners to gradually convert the square base into a circular base with the help of merging pendentives. The transition of square base into a circular or near-circular base was achieved in various ways. The simplest method was to place cross-beams at the corners to convert square into a octagon (which provided a near – circular base). The other methods were of placing corbels at the junction of the two walls at a lower point than the base from where the dome would rise and increase their length gradually upwards; by the time the base point of the dome was reached the right angle junction of the walls was converted into a smooth curve. The corbels so arranged were called pendentives. In domes, however, of larger radius and a "squat" profile the thrust on the pendentives increased and often resulted into the displacement of pendentives. The general method followed in the Islamic world was to span the corner of the square buildings by raising small arches springing from the two points located in adjoining walls. The square base was thus converted into a polygonal base. These arches were known as squinches and if required, as in larger domes, two or more tiers of squinch arches of varying sizes were built to achieve a polygonal base. It should, however, be noted that in each case, whether using pendentives or squinch arches, a centering was needed to support the dome during the process of its construction; this centering was removed only after the bricks or stones fixed in the dome had properly set in and had become strong and self-sustaining.

The construction of domes in India has been known from pre-Turkish days. But those were all instances of "false" domes constructed by using over- sailing courses of stones as in the case of "false" arches discussed earlier. In the buildings of the early Turkish sultans domes of the same type were constructed mostly by reorganizing the building material obtained from temples. Shallow domes of this type were built in the colonnade of the Quwwatul Islam mosque and in the tomb of Iltutmish. The latter, though, does not survive today. The fragments of the corbel stones were found lying near the structure by J.A. Page. The tomb is a square structure and the method of raising its dome, as described by Percy Brown, is worth quoting: "Not a little of the interest in this building lies in the principles employed in the construction of its roof, which, although most of it has fallen was probably some form of shallow dome. Curved fragments lying in the vicinity imply that it was of the indigenous type, composed of concentric rings of masonry, but owing to the excessive span it was unable to carry its own weight, so that it collapsed." It is of interest for us to note that the transition method employed, for converting the square base into an octagonal/polygonal base, used for domes in Quwwatul Islam mosque colonnade, is by placing cross-beams at the corners. In the tomb of Iltutmish this transition has been achieved with the help of squinch-arches constructed in the corners.

The earliest surviving true dome is in the Alai Darwaza providing a covering to the central hall of this structure. The dome covers a square each side of which approximately 11 meters. It is only logical that a domical roof of such dimensions would sustain if built by using voussoirs in the manner of true arches. The transition in this dome has been achieved by arranging squinches of successively narrowing spans in the manner of an alcove (semi-dome or semi-vault) in the corners. It should be recognized here that the appearance of a true dome did not by any means signal the termination of corbel and column-and-beam methods and their total take over by the architectural technology used in arches. In fact another building from almost the same period (only slightly later than the Alai Darwaza) yields evidence of the use of arch in conjunction with corbel and column-and-beam methods. This structure is Alauddin's *madrassa* located behind Quwwatul Islam mosque towards south-west and built in a quadrangle keeping an open court in the middle. The architectural feature that interests us much is to be found in the roofing of the west side cellular apartments. The "distinctive feature" as described by Page "is the method employed of supporting the flat-ceiled roof – a curious combination of Hindu and Saracenic (Islamic) devices. Thus the centre part of the roof is carried on a wide, deep-soffited pointed arch running axially north to south which, in turn, is made to carry the ends of flat roofing slabs laid to form a simple diagonal coffer characteristic of the ceiling construction of the aisles of a temple *mandapa*.". This *madrassa* building is also noteworthy for providing the earliest evidence of the use of pendentives for transition purposes. We are tempted again to quote Page for describing this method: "Another noteworthy feature of these *madrassa* cells is the use of what for want of a better term may be called a corbelled pendentive in the corners of the two higher domed chambers that break the skyline towards the ends of the façade. It is the earliest instance of this corbelled treatment of a pendentive in India (*circa*. 1290 A.D.), and is by no means an unhappy solution of this constructional problem [transition]."

The technique applied in the Alai Darwaza dome became a custom and in the subsequent period only cosmetic changes were introduced in the method of raising the dome without any major deviations from the practice of raising a centering, organizing structural elements – stones, bricks or even concrete – and cementing them and converting generally square bases into circular shapes by means of squinches, pendentives or in many cases cross-beams. The domes were embellished in different ways in accordance with the taste of the builders and same times the prevalent practice of decoration. In this context, a visible change in the shape of the dome appears when Tughlaqs assume the control of Sultanate and calls for attention. From a somewhat compressed spherical shape of the dome in Alai Darwaza, we now get to see a more "squarish" and also raised contours of the dome. This shift can be likened to a similar shift in the form of the arch from its use in Alai Darwaza in a "roundish" contour to a wider curve closer to the four-centered profile. A few structural changes also mark the Tughlaq period domes apart. We notice an attempt to provide the domes with a "neck" or more appropriately a drum to facilitate the construction and to give to the viewers a fuller appearance of the dome. The drum is an arrangement used for providing a completely circular base dome to rise. It is usually constructed in the form of a slightly raised vertical wall at the point where the transition from square to polygon terminates. Prior to the introduction of drum, the dome itself would have risen from this point. In many cases the transition was completed in the drum itself. The raised wall of the drum was of varying height depending upon the size of the dome and the requirement of its visibility. The early drums, as in the case of Ghiyasuddin Tughlaq's tomb (built during 1320-25 A.D.), were wide and short polygonal walls the inner side of which were rounded so that a circular base for the dome would be readily available. It is apparent that the drum was in an experimental stage in this building. Other constructional change in this dome related to the arrangement of stones and bricks. Percy Brown notes: "The process of construction was by means of headers and stretchers of marble attached to a brick and cement core, dowelled in with metal cramps, the headers being inserted into the core for nearly a foot, the whole having been erected over some kind of temporary centering." It seems the arrangement, as above, was made to provide additional strength to the dome. The use of metal cramps, even if it did not serve the desired purpose – holding the joints together – was not uncommon as it was practiced for a long time – the Romans used it in their bridges and so did the architects of the later period. Inserting stones deep into the cementing material was a practice used for providing additional strength to the dome, in the same manner as was done in making the thick bases of the tapering walls.

The drums gave a fresh, new look to the domes and the "stumpy" appearance of the earlier period gave way to rising and boldly contoured domes sitting on the high drums. By transferring the four-centered arch profile to the dome a different form was achieved. The process had begun under the Tughlaqs but attained completion under Akbar. Rising on a moderately high octagonal drum and surmounted by an inverted lotus motif having a finial standing vertically in the centre this dome became a distinguishing feature of Akbar's period. In the changes that followed the major one related to the shape of the dome that was modified without in any serious manner meddling with the technique of raising domes.

The structure of the dome, built on the principle of rotating an arch axially or by raising arches from all points of the circular base to finally converge at a single point at the top, did have inherent structural weaknesses. One weakness, as analyzed by George Michell, was "the change in shape from a smooth contour that occurred under the springing of the dome in the corners of the square plan, where squinch arches or spherical pendentives were used; this caused the thrusts from the dome to spread outwards, a tendency that could be partially corrected by adding dead weight above the corners". The other weakness emanated from the outward thrust generated by such a volume of hemispherical shell. If matching reactive force balancing the net effects of this thrust was not available the lower part of the dome would crack radically. The usual method to save domes from this fault was to provide reinforcement rings at the points from where the dome would rise. The device of providing "neck" or drum, discussed above, was in fact the reinforcement ring built to balance the outward thrust of the dome. But it is also true that with the increase in the size of the dome, it became increasingly difficult to contain this destabilizing thrust. An innovative method was then employed to tackle this problem. The dome began to be formed of two distinct shells instead of a single shell practiced hitherto. The two shells, outer and inner could either be joined at different points or could retain a void in between. This formation, commonly known as double dome, had the advantage of reducing the weight of the dome and of "creating great depth to aid in spanning the room below, as well as raising the external dome so that it might be more imposing". The other advantage, perhaps for harsher climatic conditions, was of "divorcing the weathering surface from the inner shell and thereby giving improved weather protection". For masonry double domes perhaps the prototype was available in the timber double domes of the earlier period built in regions like Syria where there was a persistent tradition of such structures. The early masonry double domes, from eleventh century, have been reported from Iran Later the practice spread in other parts of the world.

The double-dome in India appears at the beginning of the sixteenth century, after almost three centuries of the introduction of the "new" structural forms, arch and dome. It seems the early attempts to raise a double dome had started towards the close of the fifteenth century and in a tomb completed in 1501 AD, that of Shihabuddin Taj Khan, a Lodi noble, a half-attempt to raise a double dome was made. The feat was finely achieved in Sikander Lodi's tomb (completed c.1518 AD) where the first double dome in India survives even today. Afterwards, it became a common practice as larger domes were mostly built as double domes.

I would like to conclude this presentation by describing the basic features of Gol Gumbad of Bijapur (completed 1660 AD) which is an epitome of a structure based on the "new" technique/s-arch and dome. Gol Gumbad is the popular name of the mausoleum of Muhammad Adil Shah, the ruler of Bijapur and is dated 1656 AD. It is a square building surmounted by a massive dome, hence the name Gol Gumbad. From the outside the building gives the appearance of a "great cube" having towers in each angle and topped by a "hemispherical dome". Simple architectural technique of raising four-centered arches has been used in creating the walls of the chamber and the base of the dome. Eight tall arches have been so raised as to intersect each other at mid-point at the level of their springing. This has helped achieve circular base at the crown of these arches. "The crowns of all the arches", as noted by Merklinger, "fall upon a circle inscribed within these squares and carry the dome, which may be no smaller in diameter than the internal diameter of the circle, and which rests directly upon the crowns of the intersected arches." The circular base built thus becomes the base for the dome to rise. "The huge hemispherical dome, which is nearly 42.97m in diameter, makes it the largest space covered by a single dome in the world. It is built of bricks of varying size laid unsystematically flat in *chunam*, a lime mortar. The dome is, thus, a rigid concrete shell having no voussoirs or lateral thrusts, resting, as it were a dead weight on the mass of masonry formed by the pendentives, each, acting as a tie to the other, keeping the whole structure in equilibrium". The riddle though remains unresolved as to why Gol Gumbad is not a double dome.

NOTES AND REFERENCES

1. Rowland J. Mainstone, *Developments in Structural Form*, Architectural Press, Oxford, Edn., 1998.
2. J.C. Harle, *The Art and Architecture of the Indian Subcontinent,* Penguin Books, Middlesex, 1986.
3. Stella Kramrisch, *The Hindu Temple*, 2 vols. (pages in continuity), Motilal Banarasidas Publishers Pvt. Ltd., Delhi, 2002 (First published by the University of Calcutta, 1946 and reprinted at Delhi by the above publisher).
4. George Michell (ed), *Architecture of the Islamic World, its History and Social Meaning*, Thames and Hudson, London, 1978.
5. J.A. Page, *An Historical Memoir on the Qutb: Delhi*, Memoirs of the Archaeological Survey of India, No.22, Published originally in 1926 by the Archaeological Survey of India and reprinted in 1998, New Delhi.

6. Percy Brown, *Indian Architecture* (Islamic Period), D.B. Taraporevala Sons & Co. Pvt. Ltd., Bombay, 5th edn., 1968, p.13. (Originally published in 1956).
7. Ahsan Jan Qaisar, *Building Construction in Mughal India*, *the Evidence from Painting*, Oxford University Press, Delhi, 1988.
8. E. Baldwin Smith, *The Dome, A Study in the History of Ideas*, Princeton University Press, Princeton, 1978.
9. Elizabeth Schotten Merklinger, *Indian Islamic Architecture*, *the Deccan 1347-1686*, Oxford & IBH Publishing Co., New Delhi, 1981.