Proceedings of the First International Congress on Construction History, Madrid, 20th-24th January 2003,
ed. S. Huerta, Madrid: I. Juan de Herrera, SEdHC, ETSAM, A. E. Benvenuto, COAM, F. Dragados, 2003.

From the diaphragm arches to the ribbed vaults. An hypothesis for the birth and development of a building technique

Ignacio Arce

The aim of this paper is to discuss, on the evidence of the vaults and roofing systems present in different structures built during the Umayyad period, specially those from Qasr Harane, the birth of the first ribbed vaults as a development of the diaphragm arch roofing system, that will be latter developed in Al Andalus (Bab al Mardun mosque, Cordoba mosque, Vera Cruz and Torres del Rio churches, etc), and in the Transoxus-Khorassan Region (Sultan Sanjar mausoleum at Merv, etc). Besides, important remarks about the building techniques used in the Middle East for the construction of these arches, and relevant for understanding their structural and design concepts are also presented.

Introduction. The diaphragm arch. Origins and development

The so called «diaphragm arches» are first found in Parthian architecture, as well as in the *Hawran* (the region between present day Jordan and Syria), although in an apparently later date. This system consists of a structural self-standing arch placed transversally in a room (thrown from wall to wall), intended to support a lintelled or vaulted roof, reducing the span to be covered by that roof in the longitudinal direction of the room. The arches can be placed in series of parallel rows, defining a sequence of regular subspaces or bays, covered independently (like the ones of the Umayyad mosques of Damascus and Cordoba). Eventually they will be also arranged in the two directions of space, giving birth to composite structures: The first cross-ribbed ceilings and vaults, the birth of which will be analyzed in detail in the following.

In the first case (arches supporting a lintelled roof), the bays so defined are short enough to be spanned by stone beams set close together which carry the flat

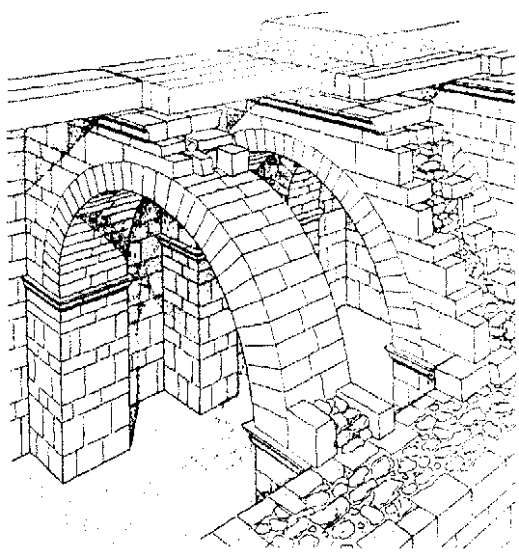

Figure 1
Hatra. Parthian Palace (Reuther 1938a: fig. 102)

floor (as can be seen at the Parthian Palace of Hatra for the first time. Reuther 1938a: fig.102 – Fig. 1–). This will give origin later to the medieval system of wooden pitched roofs and floors resting on these diaphragm arches (outstanding examples can be found in the *atarazanas* at Valencia, Poblet refectory, etc). The Roman architecture in the *Hawran* region (ancient *Auranitis*) presents numerous and conspicuos examples, as those found in the basilica at Shaqqa (Robertson 1985: p. 226 & fig. 99 – –drawn by de Vogüe in 1875– – Fig. 2), the temples at Atil, and in almost all the forts and castles from the *Limes Arabicus*. Other significative samples can be traced in singular and monumental buildings from the Byzantine (Fig. 3) and Umayyad periods confirming a continuty of use in the region throughout the centuries. It can be found also in hundreds of

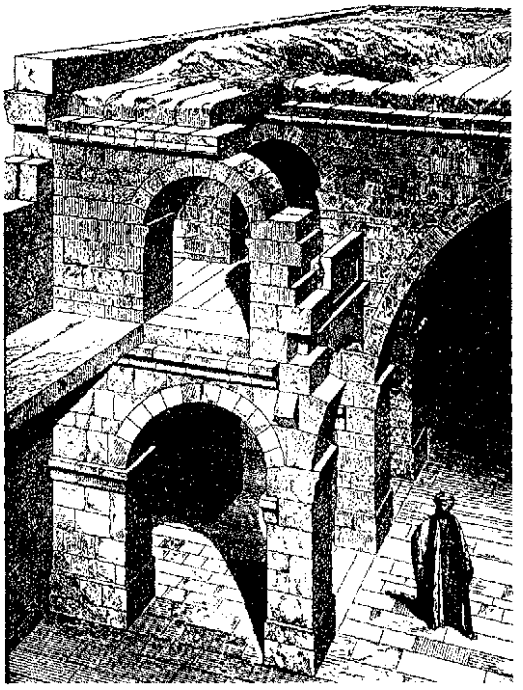

Figure 2
Shaqqa. Roman basilica (Robertson 1985: fig. 99 – –drawn by de Vogüe in 1875– –)

Figure 3
Umm Al-Jimal. Byzantine barracks

domestic houses from the Nabatean and Roman period onwards (for instance, at Umm al-Jimal or at Duma-Robertson 1985: p. 187–8 & fig.133, etc), becoming a traditional method, that will survive till nowadays (Marino and Lodino 1999) becoming the most characteristic building technique in Jordan and southern Syria.

In the second case (arches supporting a vaulted roof), transversal barrel vaults are placed resting on series of parallel arches. The first samples recorded (unfortunately not surviving) would be the ones at the Parthian Palace of Ashur (Reuther reconstruction shows clearly its disposition (Reuther 1938a: fig.100 (Fig. 4), & Andrae and Lenzen 1933), as well as those from the Sassanian palace of Taq-i-Iwan at Kkark (also known as Iwan-i-Khark, dated by Herzfeld in the late 5th C.AD). Both, Dieulafoy and Reuther, reconstructed the latter with vaults spanning between

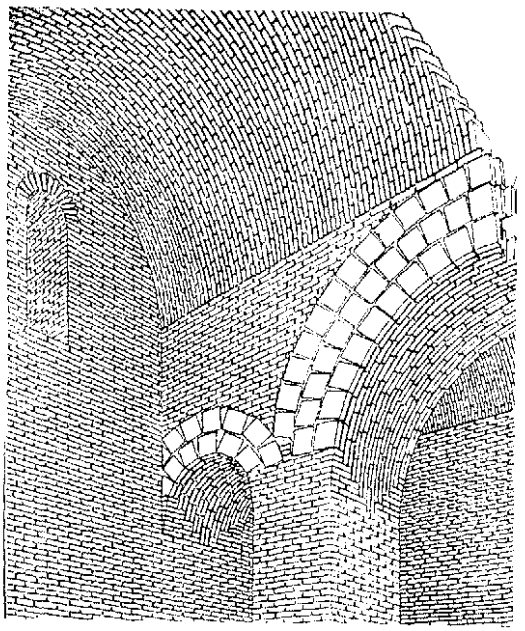

Figure 4
Ashur. Parthian Palace (Reuther 1938a: fig. 100)

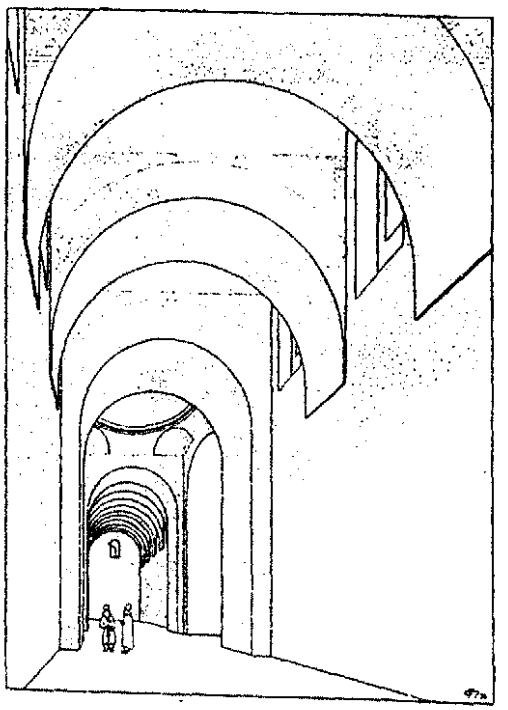

Figure 5
Khark. Sassanian palace of Taq-i-Iwan. (Reuther1938b: fig. 135)

the arches (Dieulafoy 1884: pp. 79–88 & Figs. 55–62; Reuther 1938b: fig. 135 Fig. 5). It would be found also at Sarvistan Palace (Reuther 1938: pp. & figs. 151–2), where Lionel Bier suggests also this solution in his restoration of room 12 (Bier 1979: pp. 39–40). It is noteworthy that no example nor traces of this combination of barrel vaults resting on diaphragm arches, exist from Roman and Byzantine periods in the Hawran. Suddenly during the Umayyad period the system blossoms in Great Syria and several structures are built with it: Qasr Harane, the baths of Qusayr 'Amra (Fig. 6) and Hammam As-Sarraj, the Halabat mosque and probably the audience hall at Mshatta. After the Umayyad period this solution dissapears in the region[1], but it continues in use in Mesopotamia at Ukhaidir, (a palatial complex built in the first decades of the Abbasid rule —late 8th C.AD.—) and in Iran, at the Tariq Khana mosque in Damghan, NE Iran, 8–9th C. AD —Fig. 7—), among other examples. In western architecture the only example is found at the Church of Saint Philibert in Tournous (10–11th C.AD. Dieulafoy 1884:V, p. 163 and fig.117 —Fig. 8—). The concept is undoubtedly of great relevance for the development of ribbed vaults, as it is the first case of raised vaults supported by arches.

More recently, Urice in his study about Qasr Harane (Urice 1987: p. 53) has posed the theory that

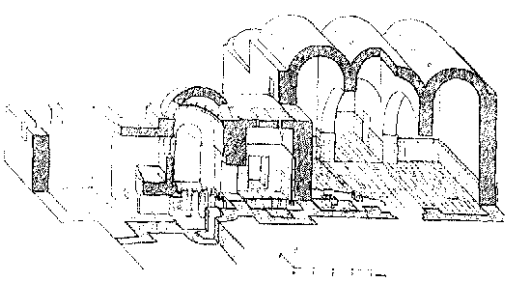

Figure 6
Qusayr 'Amra. Umayyad baths

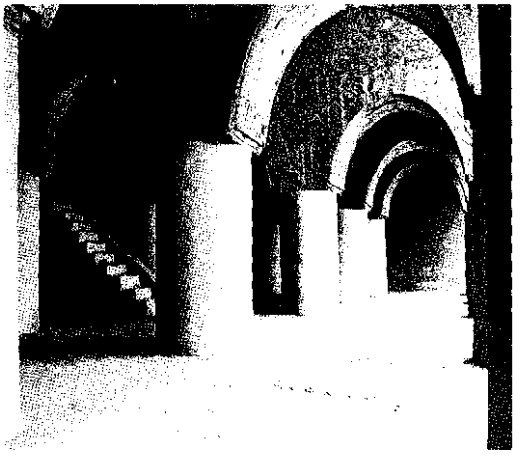

Figure 7
Damghan. Tariq Khana mosque

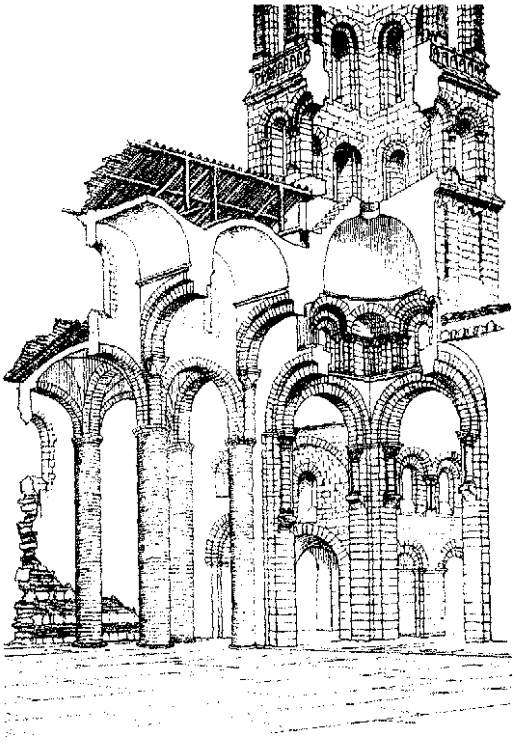

Figure 8
Tournous. Church of Saint Philibert. (Dieulafoy 1884:V. fig. 117)

this second solution would be an innovation from Umayyad period, due to the *«continuation and elaboration of an indigenous Syrian mean of monumental construction»* (Urice 1987: p. 54), rejecting its Parto-Sassanian origin because the doubts related to these first examples mentioned. Thus, he takes for granted that the earliest examples are those from Umayyad times, as he accepts Bier's dating of the palace at Sarvistan to the early Islamic period instead of the Sassanian origin suggested by Dieulafoy and Reuther. Regarding the two examples left, the Taq-i-Iwan at Khark and the Parthian Palace of Ashur, Urice points out that nothing is extant of the latter, and following Bier's opinion (Bier 1979: pp. 79–81), he rejects Dieulafoy's and Reuther's reconstructions of the former, because *«it has no basis on archaeological facts»* (Furthermore, Bier questions not only the reconstruction but also the dating, suggesting it belongs to the Seljuk period or later (!) —Bier 1979: p. 83—). Urice also points out the doubt posed by Godard: «Je ne suis d'ailleurs pas du tout certain que le coupe longitudinale d'Iwan-e Karkha ait été telle que Dieulafoy l'a dessineé. Rien n'indique en effet que ce bâtiment ait été voûte plutôt que couvert en terrasse, c'est dire qu'entre les arcs transversaux il y ait eu autrefois des voûtes plutôt qu'un plancher sur solives de bois» (Godard 1949: pp. 249–50). It must be pointed out that being Iwan-i-Khark a brick made building, it does not make sense to have been covered by stone slabs (traces of them should have been found among the debris), and in the case of a wooden flat roof, the span between two parallel arches should have been much wider than the actual one.

In my opinion, the barrel vaults on diaphragm arches scheme would have been introduced from Persia or Mesopotamia[2] (where it would have been developed and used for a long period) into the Hawran during the Umayyad period toghether with many other building techniques and materials (evidences of an intense interchange of building techniques exist during this period —see Arce 2000; Arce 2001; Almagro and Arce 1996).

On the one hand, it must be taken into account the continuous, although intermitent, cultural interchange that has existed (specially from Alexander the Great times onwards), between Mesopotamia and Syria across this border region, being the early Islamic period one of the most significative and intense of

them[3], as during that period the actual political frontier ceased to exist. Certainly Umayyad architecture and building knowledge took benefit from the conscript workforce brought together by the new rulers from the newly conquered territories of Persia, Mesopotamia, Syria and Egipt. This «melting pot» of technicians, architects and artisans would give birth, by means of mixing different architectural typologies, building techniques and decorative patterns and concepts, a brand new art, specially in architectural grounds (Arce 2000 & 2001). But in this case the building system seems just to have been introduced, not devised, in Syria during that period: It does not make sense that a brand new technical innovation, would be found in ALL the rooms of the very first building that makes use of it (as it occurs at Qasr Harane, the earliest Umayyad building using this technique), without any hesitation in its execution, that should have been the logical result of such an experimental process. Unexpectedly, they are built with a very high level of perfection, just achievable as the result of a well established and standarized procedure (compare with the «experiment» of crossing two diaphragm arches: it is carried out in a sole room, and in a quite awkward way —see below—).

On the other hand, all the existing evidences suggest a Mesopotamian/Iranian origin for both techniques (lintels and vaults on arches), as well as for the diaphragm arches and the barrel vaults themselves (the origins of which can be traced back in Mesopotamia during the Babylonian period[4]). The Parto-Sassanian origin of the diaphragm arch is also clear, as the oldest samples known are from that period & region (Ashur, Hatra, Kharkh), being probably introduced into the Hawran region during early Roman times (the examples from Assur and Hatra have been dated without discussion back to the Parthian period), meanwhile no example earlier than Nabatean-Roman Period has been found in the Hawran or in other places in Syria.[5] If both technical improvements are from Masopotamian/Persian origin, it make sense that the combination of both, would have been also devised in that region.[6] Besides, the system continues to be used in Iran and Mesopotamia after the Umayyad period, meanwhile it ceased to exist in Syria after the fall of the Umayyad rule.

The Umayyad examples. The case of Qasr Harane

This isolated Umayyad «desert castle», placed 80Km. to the East of Amman in the Syrian desert is, for several reasons, a building of extraordinary architectural innovation. Apart from other significative constructional features (semi domes on squinches, prefabricated elements in gypsum, etc. —see Urice 1987 & Arce 2000—), it is the most outstanding building regarding the use of barrel vaults on diaphragm arches, as almost all the rooms were covered with this system, and because it is certainly the earliest among all the Umayyad examples (consequently the oldest sample still surviving in Syria) to use this method.

Regarding the construction of the diaphragm arches themselves at Qasr Harane, two different building

Figure 9
Qasr Harane. Arch building technique I

techniques can be noticed. In both cases roughly cut flat limestone voussoirs and gypsum based mortar are used: In the first case, the springers of the arch are built without any centering, setting the stones flat in projecting radiated courses (*«por lechos»*, i.e. «horizontally», or more precisely, parallel to the axe of the room) up to cover the correspondent extent of 1/4 or 1/3 of the span), meanwhile the central stretch is built placing the stones vertically perpendicularly to the axe of the room (*«por hojas»*) (Fig. 9). In the second case, meanwhile the springers are like in the previous one, the central stretch is built with the help of two lateral permanent ribs, «forms» or «centerings» of precast gypsum, that help to continue raising the arch without a traditional centering (just a light support to keep these pieces in place) is needed. These elements offer the required temporary support to the new courses (that are built leaning against them) and help to define the desired profile of the arch, working thus also as a form. Once the arch is finished they remain embedded in the structure (Fig. 10).

Both systems are from Mesopotamian/Persian origin: The first one is already found in the Parthian palace of Ashur (although there are used bricks, instead of flat stones —see fig. 4—). The second one is found throughout Persia, in the Umayyad Palace at Amman Citadel (Fig. 11 Arce 2000: p. 118- 20 & figs. 14a & 15 and Almagro and Arce: pp. 28–9 & Fig 6), and also at Ukhaydir (Fig. 12 —from Reuther 1912—). In Ukhaydir the two permanent pre-cast ribs span all the width of the opening (similar, but smaller samples of full-span precast ribs can be seen at Harane itself, in

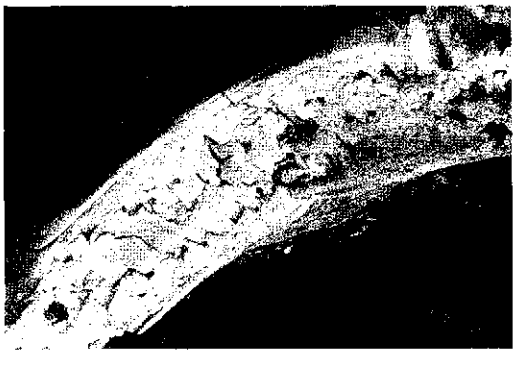

Figure 10
Qasr Harane. Arch building technique II (Gypsum precast embedded ribs)

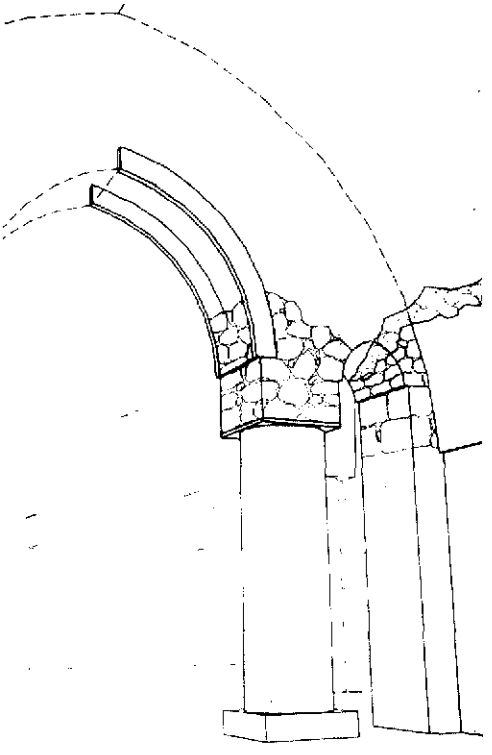

Figure 11
Umayyad Palace at Amman Citadel (Gypsum precast ribs)

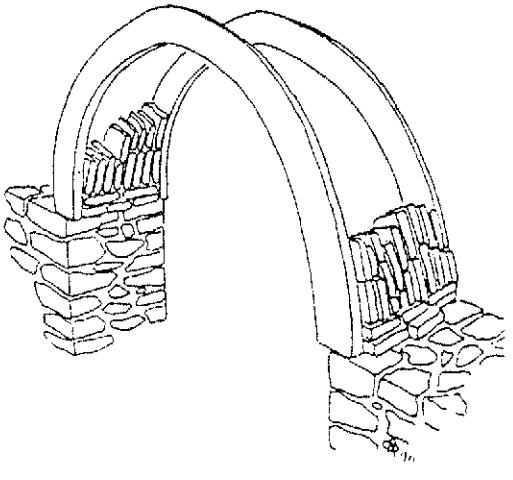

Figure 12
Ukhaydir. Gypsum precast ribs (Reuther 1912)

the row of small windows at rooms 29 and 59, built with these elements —Arce 2000: fig 14a—).

The Vaults are built following the Mesopotamian origin method of rings of vertically laid courses leaning against the end walls of the room to be roofed («por hojas»). The space left in the central area is covered following the same principle, just turning 90° the way the stones/bricks are laid (see Fig. 9). In our case instead of bricks, flat limestones are used.

The cross ribbed ceiling of room 61 at Harane. The genesis of the ribbed vaults

Room 61 is the most unusual chamber of Qasr Harane, it just measures 3.50 by 3.90 and is covered by an extraordinary combination of two diaphragm arches displayed perpendicularly to each other. They spring from the midpoint of the walls of the room from a triple recessed corbel, giving as a result a crossed structure that divides the ceiling into four square areas covered by that support four sets of coffers (Fig. 13). These coffers, also with a clear Parto-Sassanian origin, consist of recessed squares rotated at 90°, and are similar to the ones supported by the squinches in room 51 (Urice 1987: fig. 25) and to those from Amman Citadel Throne Hall (Arce 2000). Jaussen & Savignac suggest that the innermost part of the coffers could have housed an small dome, but taking into the account the antecedents and parallels of those coffers, this hypotesis does not seem to have a sound basis.

The importance of this ceiling is capital for the study of the birth of the ribbed vaults as it would represent the earliest antecedent of the ribbed vaults that later are to be found in Spain, Armenia and in the Transoxus region. It is actually the «missing link» that relates undoubtedly, the cross ribbed ceilings and vaults to the diaphragm arch technique, clarifying and demonstrating their origin.

Before the restoration carried out in the 80's by the Department of Antiquities, it was clear (Fig. 14a&b; Urice 1987: figs. 37–8) that for the construction of

Figure 13
Qasr Harane. Room 61. Cross ribbed ceiling. Present state

Figure 14a&b
Qasr Harane. Room 61. Cross ribbed ceiling. Before restoration (Urice 1987:figs. 37–8)

these arches it had been used permanent precast gypsum ribs («embedded centerings or forms»), being set first one of the arches, and immediately after the second one, that consists of two sections leaning against the crown of the first one.[7]

Development of the system

The next step in the development of this design concept led to cover a square room with two pairs of parallel arches crossing each other at 90°, instead of single ones. They can be placed parallel to the walls of the room or diagonally, springing from adjacent walls. At the *Tornerias* mosque in Toledo (2nd half of the 11th C.), it can be found an outstanding sample of the first solution, that divides the ceiling into nine square sections or bays, that on their turn, are covered by pairs of single arches crossing at 90° springing from the mid points of the square bays (as in Harane), or from the corners.

Increasing degrees of sophistication are achieved when both possibilities are combined and eight arches arranged in four pairs, define an eight point star (two rotated squares). The arches can also span from the corners of the room to the midpoint of the opposite walls, giving as a result pairs of arches parallel but not in axe, that are interlaced creating an interesting tridimensional braid effect (see the SE bay vault of Bab al Mardun mosque in Toledo. Almost all the possible combinations (Fig. 15) can be found at this well known mosque from the 10th.C. AD (up to now it was the very starting point of this «chain» of examples): It offers an incredible catalog of solutions that are even combined one atop another (S, SW, NW & NE bays). More refined in their execution are the examples from the *maqsura* at the Corboba mosque (belonging to the enlargement commissioned by Al Hakam II —also 10th C. AD— Fig. 6).

The first Christian building in the Iberian peninsula that presents this solution is the Vera Cruz church at Segovia (12th.C.AD): The stone vault of the upper central chamber of this outstanding central-plan church is covered by a rather ackward and crude solution consisting of two pairs of ribs crossing at 90° quite close to each other (Fig. 17). It can be seen that the second couple of arches abut on the first one (as in Harane). The next step, that foreshadows gothic solutions, is found at the Holy Sepulcre church in Torres del Rio (late S.XIII): It was built with pointed arches (Fig. 18) and using a carefully cut and dressed stone elements[8], Several religious and civil *mudejar* buildings will make use of this system during the 12th, 13th.and 14th.Centuries (like the castles at Villena and at Biar — Ferre de Merlo 2000—). Later, during the Renaissance, Andrés de Vandelvira will recover and apply the concept of the two pairs of arches crossed at 90° at the Renaissance church of S. Ardrés in Ubeda. His son, Alonso, records in his treatise, the way of building it, existing some examples of this late Renaisance adaptation of the solution by other architects.

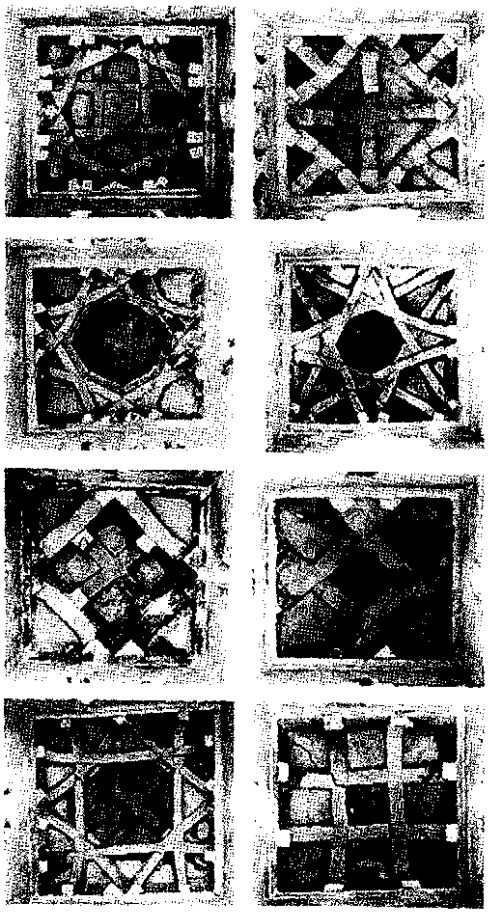

Figure 15
Toledo. Bab al Mardun Mosque. Ribbed vaults

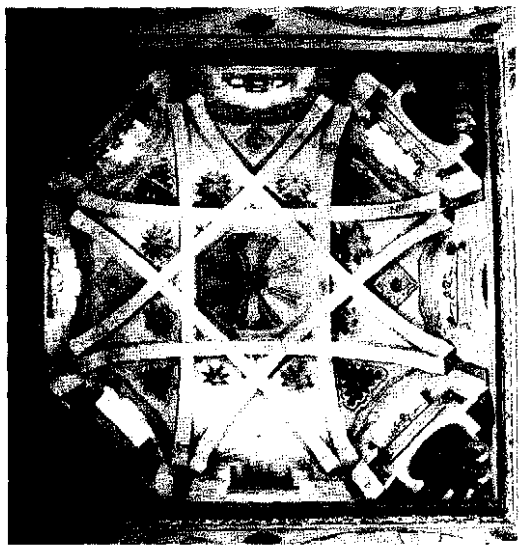

Figure 16
Corboba mosque. Ribbed vault from the *maqsura*

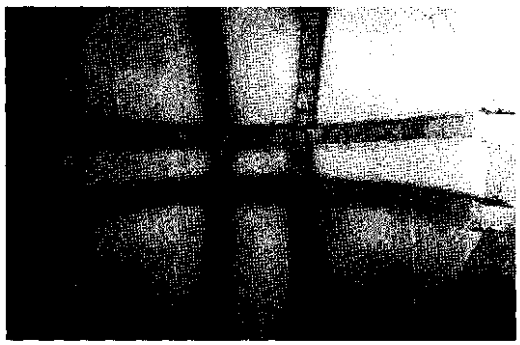

Figure 17
Segovia. Vera Cruz church. Upper central chamber. Ribbed vault

Several other vaulting traditions that stem out from this same concept deserve to be reviewed.

Timurid stellate vaults

It is likely that experiments with the simplest form of stellate vault gave rise to those of greater complexity. This is the cases of those found in the Seljuk and later

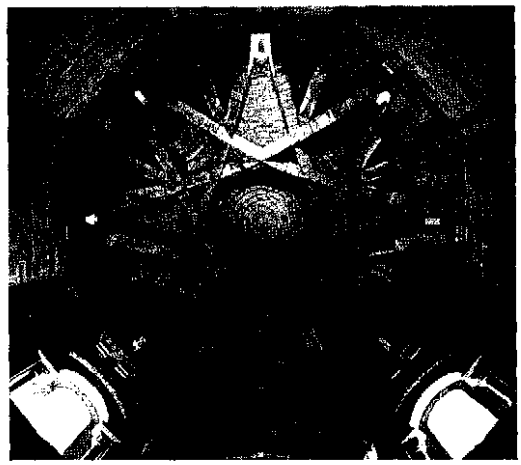

Figure 18
Torres del Rio. Holy Sepulcre church. Ribbed vault

in the Timurid architecture, where the number of these pairs of parallel brick arches rotating arround the centre of the room will multiply, giving birth to the so called «Stellate vaults» (Golombek & Wilber 1988: pp. 169–173 & figs. 42–45): *«The surface of the dome is broken up into multiple planes or facets, but the geometric scheme is preserved as a «skeleton» of arched ribs. These arched ribs interact within the pattern and become the arch net, filling pendentival areas, while delineating with their crowns a star poligon in the center of the dome»* (Golombek & Wilber 1988: pp. 169). The ribbed dome from Sultan Sanjar at Merv (Fig. 19) offers an outstanding sample of this development.

Gavits' vaulting

A singular case of ribbed vaults are those that cover the Armenian *«gavits»* (a kind of square narthex, placed at the western entrance of the Armenian churches, and used as an asambleary room —or *jamatun*—). In this case, four diaphragm arches displayed in pairs perpendicularly each other (and parallel to the walls of the square plan room), on which rest quarter sections of barrel vaults, defining a sort of ribbed cloister vault, with a central square uncovered bay, that gives light to the room (Fig. 20).

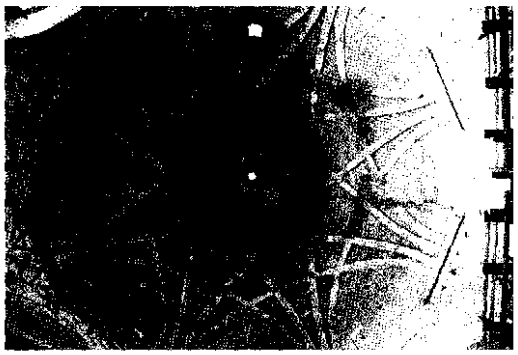

Figure 19
Merv. The ribbed dome from Sultan Sanjar mausoleum

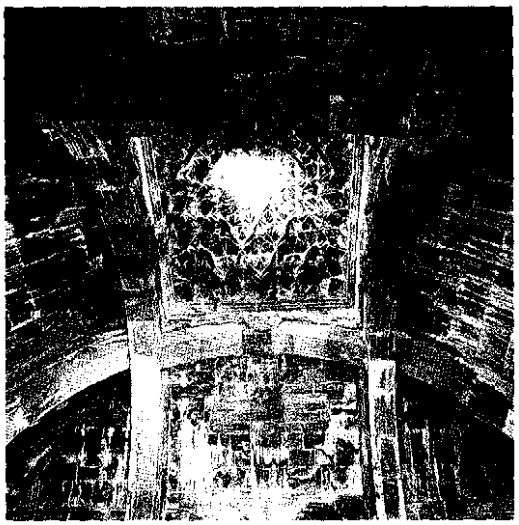

Figure 20
Gandzasar monastry (Azerbaidjan). Gavit's vault

As can be seen, it is a particular case of the simplest solution, but despite its simplicity (and because its clear structural and spatial concept), it will become a typical and distinctive structure of Armenian monastic architecture. Its design concept, and the date of the first samples dated (IX–X C. AD) suggest at least a parallel development, from a common root (Armenia before being incorporated to the Sassanian empire was a buffer state in between Bizantine and Sassanian empires).

Rib arches as temporary centerings. The case of the «*Quadripartite lanceolate vaults*» (pointed and ribbed cloister vaults) and the Roman cross groined «ribbed» vaults

Special attention deserve the analysis of a different kind of oriental «ribbed» vaults, as they provide significative information about a different concept in the use of arches for vaulting. This may offer an explanation for some details in the construction of actual ribbed vaults in Khorassan and Turan.

More loosely related to the vaulting concepts exposed up to now (and also different in building procedure) are the so called «*quadripartite lanceolate vaults*» (so called by Herrmann 1999: pp. 57–9 & 135) widely found in Central Asia and in the Khorassan, mainly during the Seljuk period (11th and 12th C. A.D.). Examples from earlier period may exist, like those from the Greater Kyz Qala at Merv (some authors date it back to the first Abbasid period – 8th to 9thC.A.D. –) or at the Yakkiper Köshk at Merv, as well as in other places in the Khorasan region (the area nowadays between NE Iran and Turkmenistan) and in Turan (ancient name of the Centroasian region). The ribs that we found in these cases belong, as we will see, to the group of arches or ribs intended as temporary centerings of forms.

The usual building procedure of these brick (or adobe) vaults resemble (and combine) the one of the Sassanian *squinch vault*,[9] and that of the (also traditional Sassanian) parabolic-in-section barrel vault built without centering (Reuther 1938b: p. 499–500 & fig.129). Both, the *squinch vault* and the «*quadripartite lanceolate*» one, are built starting from the corners of the room to be roofed, without using any centering: In the case of the squinch vault, a series of small arches are placed diagonally across the corner of the room forming half-cone-shaped squinches that continue rising in a series of concentric brick courses, until the four half cones so formed meet up to form the vault itself (Fig. 21 –Reuther 1938b: p. 501 & fig.130—).

In the case of the «quadripartite lanceolate» vault, pairs of bricks standing almost vertically and leaning against each other are placed in the corners of the room. New and consecutive «rings» of vertical-placed bricks abut on the first ones, gaining each ring an increasing curved setting projecting inwards (as in the mentioned Sassanian parabolic barrel vaults). The result is a sort of «pointed» cloister vault, the

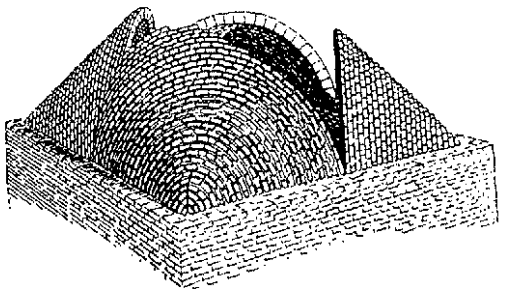

Figure 21
Squinch vault or *Balkhi vault* (Reuther 1938b: fig. 130)

geometric definition of which would be the intersection of two parabolic/pointed barrel vaults, instead of the usual intersection of semicircular barrel vaults (Herrmann 1999: fig.52).

When the span of the room is too big, pairs of reinforcing headers ribs (*a sort of header arches — «arcos de cabeza»* –) are placed near the corners in order to offer a better and more stable support to the next rings of bricks. So, after the first corner rings are put in place, a series of new ones are set projecting out a few centimeters from the former ones, defining the mentioned ribs.[10] In these vaults the pairs of ribs are placed close to the corners of the room, and they end where they meet each other, not being thus complete true arches[11] (Fig. 22). These parallel ribs are used as

Figure 22
Merv. Yakkiper Köshk, room 6 . *Quadripartite lanceolate vault* (Herrmann 1999, fig. 51)

temporary support for the central section of the vault built in between them. This central stretch can be closed easily setting the remaining rings leaning against them: The result is a sort of ribbed cloister vault[12] of bricks set vertically that does not require any centering for its construction.

Discussion

This method proves that the conceptual improvement that can be seen in some Byzantine barrel vaults, had been already devised in the Persian region of Khorassan and applied for the construction of a more complicated structure. Thus, it would be the link between the Mesopotamian-Sassanian barrel vaults and those Byzantine ones that use embedded transversal arches in order to support the intermediate stretches of vault (that in their turn, are built with the – also Mesopotamian— method of rings of vertical bricks resting on these header arches – –Choisy 1883— 1997: pp. 31–43 & figs. 30–41).

Conceptually this technique is much closer related to the above described Persian one of the precast gypsum centerings/ribs for the construction of arches (see above the «second solution» present at Harane, Amman & Ukhaidir). Consequently, it would be also conceptually related to the group of Roman «ribbed» cross groined vaults, as in all these cases the «rib arches» are not true ones but just a sort of embedded centering or form, intended as a temporary support during the construction, becoming afterwards part of the arch (or of the vault) itself, without an specific role, once the construction is finished.[13] Similarly, in the Roman concrete vaults the arches are embodied in the vault itself as intended merely as temporary supporting or coffering means during construction (Choisy 1873–1999 lams.VII–IX). This poses a series of interesting questions: Were the Romans aware of these oriental improvements? May these techniques have influenced somehow the development of the Roman technique of embedded rib cross groined vaults? The question remains open.

Appendix. Other Building techniques devised for arch construction in the Levant. The antecedents of the «Tas de Charge»

The aim of this section of the paper is to present the result of the research conducted on the building

techniques used for the construction of (diaphragm) arches in the Syrian region of *Hauran* from Roman to Islamic times. Earlier we have described in detail the methods for arch construction from Mesopotamian-Iranian origin, now special attention will be paid to the methods developed in this region during the Roman period An special stress is done on the peculiar shape and arrangement of the voussoirs of certain Roman masonry arches, and the way the centerings were designed and placed to built them. It will be shown how this method survived until the Umayyad period, and how it can be regarded as the technical antecedent of the «Tas de Charge», essential for the development of the Gothic ribbed vaults.

As in the previous cases, in order to reduce the extent that the centering must span when building an arch, the first courses or voussoirs are projected towards the centre of the arch, even in horizontal layers, without the help of any centering. Then, different solutions can devised to span the central gap: Previously we have described in detail the Mesopotamian-Iranian methods that can even avoid totally the use of a centering, by means of the use of precast gypsum ribs used as permanent centering/coffer; now we will study the Roman ones devised in a region also lacking of timber to built wide-span centerings. In traditional Roman construction, the last voussoirs or courses of this lower section of the arch, often project towards the center of the arch further than the intrados profile of the arch, in order to support the centering required to complete the work. Relevant and well known examples of this are those from the *Pont d'Ambrussum*, or the *Pont du Garde* (Fig. 23) (Adam 1984: figs.420–1 & 662 and also Choisy 1999: P.112 & figs.77–78). This allow to reduce the dimensions of the centering as well as the timber sections required to built them. Besides, the direct thrust exerted on these special voussoirs, by the new upper ones placed with the help of the centering, counterbalance the one exerted by the centering itself, as both rest on that cantilevered projecting voussoirs. Once the work was finished these projecting elements were usually carved away, although in other cases (as the mentioned bridges) they were left in situ, due to the utilitarian nature of the construction.

In the Levant, a more sophisticated and efficient version of this method was developed in the Syrian region of *Hawran* during the Roman period (all the examples belong to the 2nd. C.AD). The method

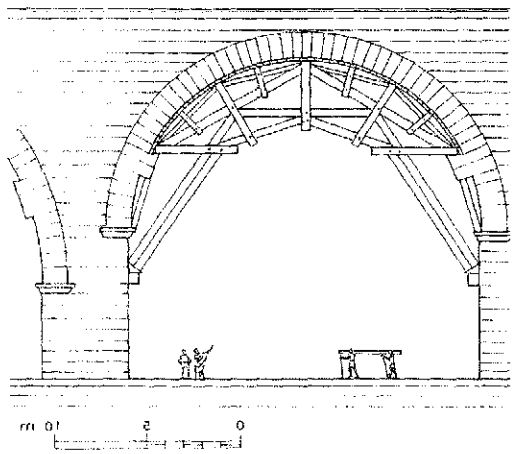

Figure 23
Pont du Garde (Adam 1984: figs. 420)

consists in embedding deep into the lateral walls (the spandrels of the arch) these special voussoirs, by projecting them also «inwards» (futher than the extrados profile of the arch). As in the previous case, it is not neccessary to use any centering in the construction up to the level of these special voussoirs, meanwhile for the central stretch remaining, just a small centering is required. This method will be kept in use during Umayyad period and extensively used in all kind of arch/vault construction.

A related antecedent of the design concept of this system could be traced in the Roman construction of lintelled arches without centering: Choisy points out the samples from the Verona amphitheatre (Choisy 1999 [1873]: p. 117), where the lintelled arch consist just of three pieces: the two corbelled «springers» embedded in the wall (the weight of which counterbalance the projecting section of the springer) and the keystone usually placed later. In our case the actual springer voussoirs that projects inwards and serve as support for the centering are also cantilevered pieces, being also embedded in the wall, and counterballanced by the weight of the courses from the spandrels of the arch (this system is also widespread in the *Hawran* region).

In these «oriental» cases that have been analyzed, although no traces of the «outer» projecting sections of the voussoirs survive (they were carved away

because belonging to civic and religious buildings and not to bridges as in the western samples), it is clear that these pieces were carved in this way, being afterwards cut away. These projections were just needed to support the centering during the construction of the central section of the arch, meanwhile the «inner» embedding offers a permanent and better bonding and consequently a better counterbalance to this cantilevered element, during and after the construction process.

Furthermore, this corbelled voussoirs (the uppermost of this lower section of the arch) is in some cases carved with a bent shape in order to improve ever more the bonding into the wall, offering at the same time a better counterbalance for the temporarily thrust of the centering. It also distributes better the arch thrust once the construction is completed and the centering dismantled, because the upper faces of this bent piece offer the ideal springer bed for both, the radial voussoirs of the upper part of the arch and the horizontal courses of the spandrels (see below). Another distinctive characteristic of these projecting voussoirs is that they are the only ones consisting of two adjoining pieces, placed one beside the other (due to its longitudinal shape and its corbelled function), instead of the single ones used in the rest of the arch voussoirs. It is interesting to note how these pieces work actually as a *«Tas de Charge»*, i. e. those lowest courses/voussoirs of a vault or arch laid horizontally and bonded into the wall offering an upper face with the required pitch to continue the arch. This arch springer, that will become essential during the Gothic period (as described by Viollet le Duc), has in these examples its more clear (and fully developed) antecedent .

The different building procedure used for the construction of the two sections of the arch can be also discerned from the clear difference between the way the voussoirs were cut in the first courses of the arch from those that conform the haunches and the

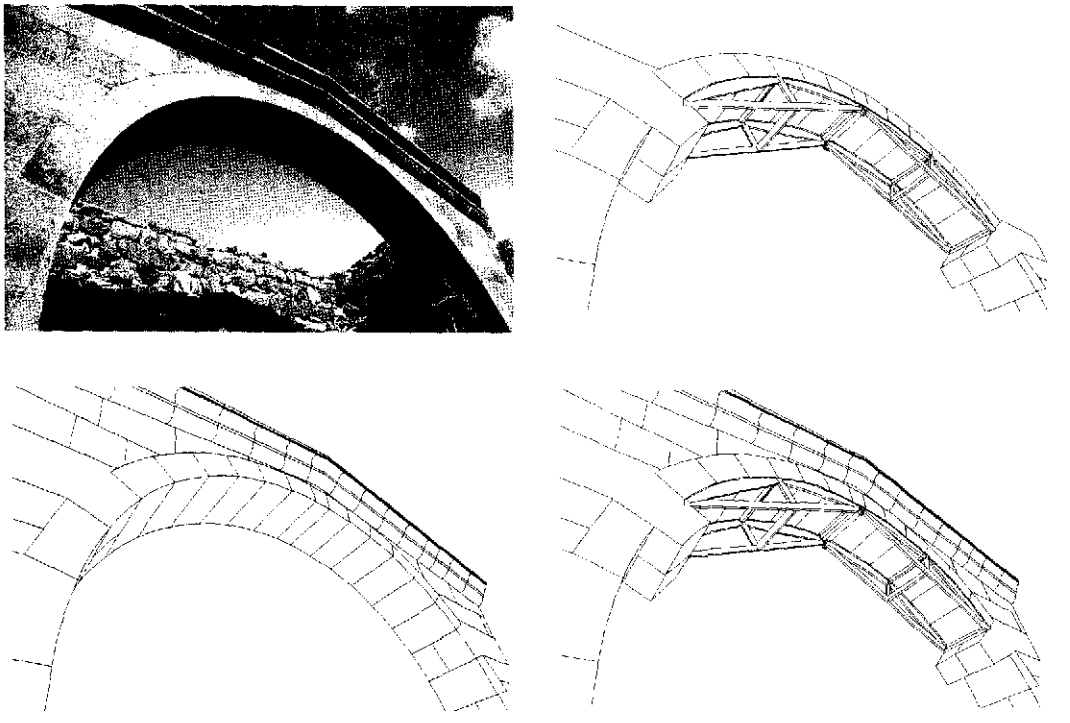

Figure 24a-d
Atil.North (Roman) Temple. Hypothesis of building process

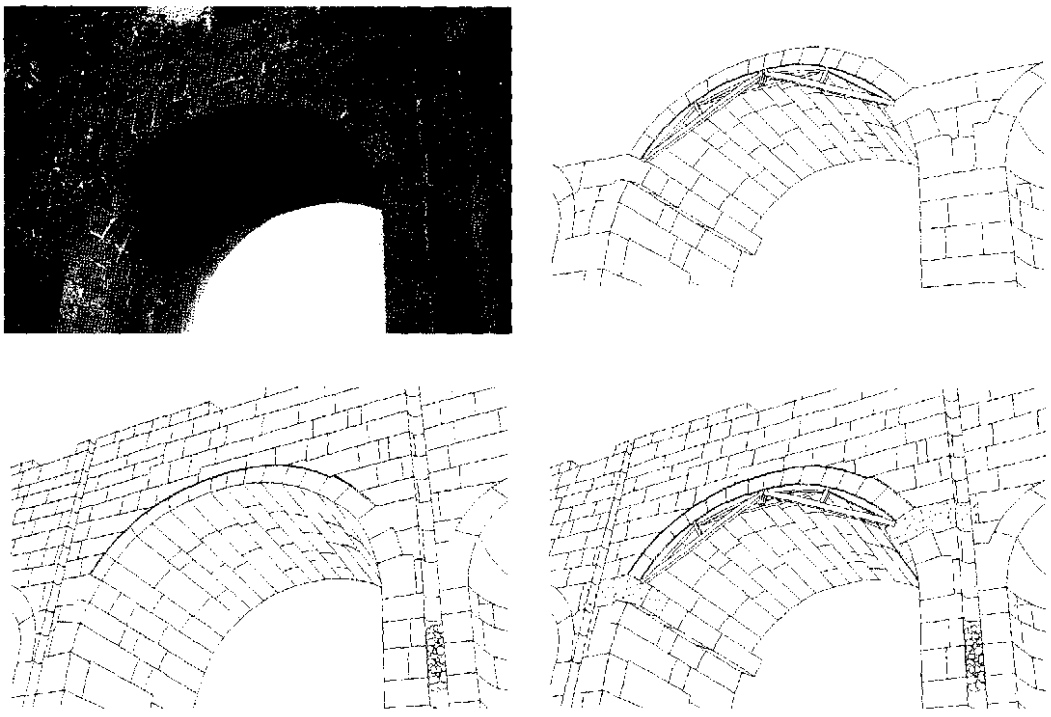

Figure 25
Shahba (former Philipopolis). Roman baths. Arch from the *frigidarium*

crown. The latter define a perfect extradosed arch profile, meanwhile the former usually have a stepped extrados, being interlinked with the masonry work of the wall fabric. Also a slight difference in the curvature of the intrados denote these two phases of construction (figs. 24a–d&25).

In the case from the North Temple at Atil, we can find a subtle improvement that toghether with the exquisite perfection of the dressing of its basalt ashlars, demonstrate the high level of sophistication and quality achieved, based on a precise construction efficacy in controlling the means and resources available. In addition to the mentioned features, the *«Tas de Charge»* voussoirs present in this case a shallow recess cut in the upper face of these special pieces, in order to prevent the sliding of the first voussoir of the upper-central section of the arch that rest on that piece and on the centering that springs also from it (fig. 24).

The examples from the Roman baths at Shahba (former Philipopolis) (fig. 25a-d) and Bosra (the capital of the *Auranitis* region), present the basic features described, although the cutting of the basalt ashlars is not so precise, because they were intended to be concealed behind a marble veneer, of which just the holes for the metal cramps remain. Nevertheless, this rougher finishing allow to notice better the mentioned slight change of curvature in the arch intrados, and the general concepts of the design. In these two buildings can be also traced the use of this same concept for the construction of semidomes.

In the Vestibule of the Umayyad palace at Amman Citadel can be found the adoption of this system in the construction of the four arches of the central space of the building: In this case the corbelled voussoirs project outwards further than the profile of the extrados and have a bent upper face, meanwhile the lower one follows the line of the radial joint (fig. 26).

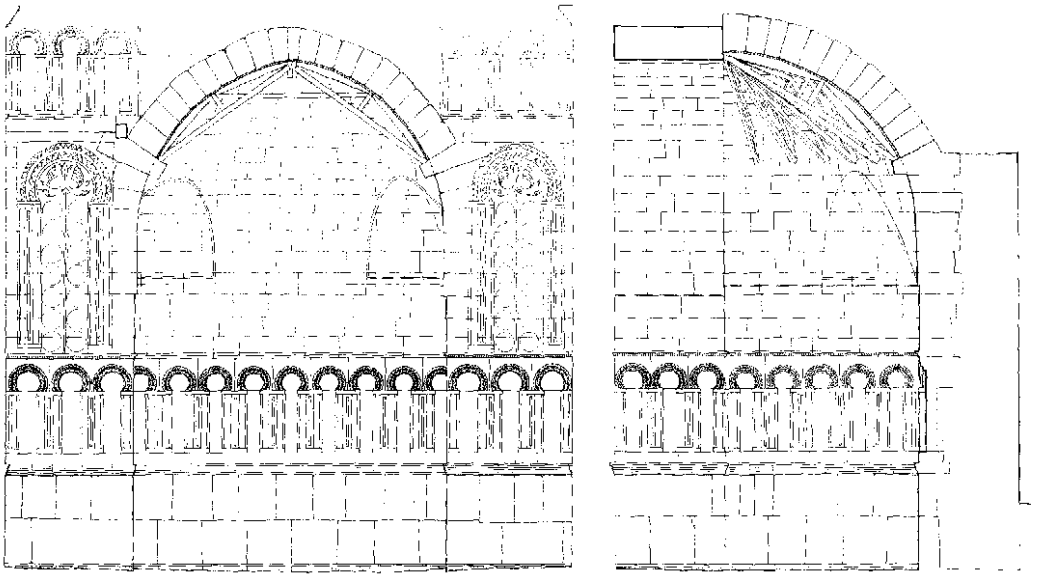

Figure 26
Umayyad Palace of Amman. Vestibule. Hypothesis of building process

There are evidences that prove that a similar system was also used for the construction of the lateral semidomes (as in the Termae from Bosra and Shahba): On top of the first horizontal projecting courses (where the «counterfait» squinches are carved –Arce 2000; Creswell 1969—), was built the upper section of the semidome (a «true» one, with proper spherical radial joints). This upper section was built springing from the uppermost course of the horizontal layers, that had been carved with the mentioned «Tas de Charge» profile, i.e.: offering an upper face with the required pitch to start the true dome (this was ascertained from the study of its extrados during the restoration of the monument carried out by the Author). The semidome abuts also on the above mentioned central arches (Fig. 27) and was built most probably on small centerings[14] that should have been supported by projecting sections of the mentioned transition course (that would have been cut away afterwards, as in the case of the arches).

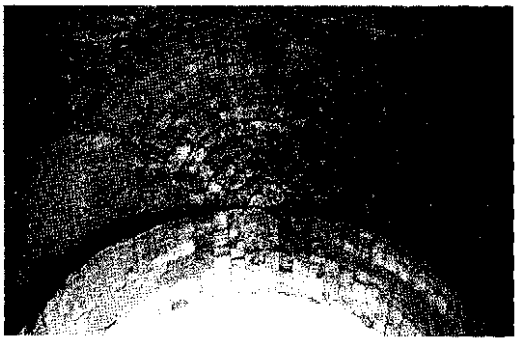

Figure 27
Umayyad Palace of Amman. Vestibule. Semidomes resting on horizontal corbelled courses (with counterfait or «false» squinches carved out on them), and leaning against central arches

Notes

1. For a detailed discussion (up to 1969) on the origin of this system, see Creswell 1969: pp. 444-49 & Godard 1949: pp. 244–50.
2. It is noteworthy that before an adequate assessment and dating were carried out, the first studies on Qasre Harane emphasized the «Mesopotamian» character of

the building in construction and decoration (Jaussen & Savignac 1922: pp. 114–21) or even postulated on the same basis a Sassanian origin (Dieulafoy 1913:15 and Warren 1977:49).

3. This can be traced very clearly for instance in the «classical» decorative patterns present in the Parto-Sassanian architecture since Alexander's period, that in some cases were «reintroduced» in Syria during Umayyad period (see Arce 2000).
4. Strabo in *Geographica*, Book XVI Chapter 1.5 makes reference to the vaults that covered the houses in Babylonia and Susiana because of the lack of wood fit for roofing.
5. Nevertheless, Reuther follows the theory of Diez, suggesting that the diaphragm arch *«seems to have originated in southern Arabia and to have travelled from the Yemen north with the migrating groups of Azdites and Himayarites, who, when they settled in Syria and Mesopotamia, which was then under Arsacid control, introduced it to these regions, where, however, it came to be executed entirely in stone»* (Reuther:425 quoting from E. Diez, Die Kunst in der islamischen Völker, Berlin, 1915, pxii.). The fact is that no archaeological evidence exists to support this hypothesis nor traces of this technique survive in Yemen.
6. Besides, it must be pointed out that although Bier and Goddard reject skeptically Dieulafoy's and Reuther's reconstructions and dating of the earlier examples of vaults on diaphragm arches to the Sassanian period, they fail to provide sound evidences to support firmly their own hypothesis of dating. It is highly unlikely to have such an important development coming «out of the blue», meanwhile several evidences point out to the mentioned Mesopotamian-Iranian origin.
7. These photographs come from to the Rockefeller Museum photographic archive (at Jerusalem) and were taken in 1940 (Inventory #: RMP 23.149 & other two without inventory number).
8. It is noteworthy that both churches were built by the Temple order, which had gain a thorough knowledge of the oriental building techniques in the Near East.
9. The squinch vault is called «*balkhi* vault» in Central Asia, in reference to the city of Balkh (present day Mazar-i-Sharif) (see Herrmann 1999).
10. In other cases, the section of the vault varies in regular stretches defining series of raised ribs (and recessed areas), that in these cases run across the whole surface of the vault (see room 5 at Yakkiper Köskhk in Herrmann 1999: fig. 112).
11. These arches define its characteristic «lanceolate» shape, that led Herrmann to give this name to them (Herrmann 1999).
12. This led Pugachenkova, instead, to call them «monastery vaults» (for «cloister vault»). (Pugachenkova, 1958).
13. These ones require just a light support themselves during their construction.
14. In the construction of the traditional Jordanian houses, these small centerings required for the construction of the diaphragm arches, are still used, showing the pervivence of this technique in the vernacular architecture (Marino and Lodino 1999: fig. in p. 37).

Reference List

Adam, J. P. 1984. *La Construction Romaine. Materiaux et Techniques*. Paris: Picard Ed.

Andrae, W. & Lenzen, H. 1933. Die Partherstadt Ashur, in *Wissenschaftliche Veröffentlichung der Deutschen Orientgesellschaft* 57. Leipzig.

Almagro, A. & Arce, I. 1996. El Alcázar omeya de Amman, crisol de técnicas constructivas. In proceedings of *I Congreso Nacional de Historia de la Construcción*. Pp. 25–30. Huerta, S. ed. Madrid: Instituto Juan de Herrera, CEHOPU & CEDEX.

Arce, I. 1996. Elementos y sistemas constructivos antisísmicos en la antigüedad. Aplicación a la restauración de estructuras históricas. In proceedings of I *Congreso Nacional de Historia de la Construcción*. Pp. 39–47 Huerta, S. ed. Madrid. Instituto Juan de Herrera. CEHOPU & CEDEX.

Arce, I. 2000. Un tipo inédito de trompas en la arquitectura omeya. In proceedings of *III Congreso Nacional de Historia de la Construcción*. Pp. 37–47. Huerta, S. ed. Madrid: Instituto Juan de Herrera, CEHOPU & CEDEX.

Arce, I. 2001. The Early Islamic Stucco Techniques and the Parto-Sassanian tradition. Continuity and Change. In *Lo Stucco, Cultura, Tecnologia e Conoscenza* (Proceedings of the XVII International Conference «Scienza e Beni Culturali». Pp. 107–129. Biscontin, G. & Driussi, G. eds. Padova: Edizioni Arcadia Ricerche.

Choisy, A. [1833] 1999 *El arte de construir en Roma* (translation into Spanish of L'art de bâtir chez les Romans). Madrid : Instituto Juan de Herrera. CEHOPU & CEDEX.

Choisy, A. [1883] 1997. *El arte de construir en Bizancio* (translation into Spanish of L'art de bâtir chez les Byzantins). Madrid: Instituto Juan de Herrera, CEHOPU & CEDEX.

Creswell, K.A.C. 1969. *Early Muslim Architecture*. 2nd. ed., vol.1 part 2 Oxford: Clarendon press.

De Vogüe, C.1865–71. *Syrie Centrale: Architecture Civile et Religieuse du Ier au VIIe siécle*. Paris.

Dieulafoy, M. 1884. *L'Art Antique de la Perse*. Paris: Librairie centrale d'architecture.

Diez, E. 1915. *Die Kunst der Islamischen Volker*. Berlin-

Neubabelsberg: Akademische Verlagsgesellschaft Athenaion.

Ferre de Merlo, L. 2000. Bovedas nervadas en el Castillo de Villena. In proceedings of *III Congreso Nacional de Historia de la Construcción*. Pp. 303–7. Huerta, S. ed. Madrid.Instituto Juan de Herrera, CEHOPU & CEDEX.

Godard, A. 1949. Voûtes iraniennes. In *Athar-e Iran 4*: Pp. 187–156.

Golombek, L & Wilber, D. 1988. *The Timurid Architecture of Iran and Turan*. 2 Vols. Princeton Monographs in Art and Archaeology XLVI. Princeton: Princeton University Press.

Herrmann, G. 1999. *The Monuments of Merv: Traditional Buildings from the Karakum*. London: The Society of Antiquaries of London.

Jaussen A.N. & Sauvignac, R. 1922. *Mission archéologique en Arabie,V.III: Les Châteaux Arabes de Qeseir 'Amra, Harâneh, et Tuba*. Paris: Paul Geuthner Ed.

Marino, L. & Lodino, M. 1999. *La casa tradizionale nei villaggi della Giordania*. Verona: Cierre Edizioni.

Pugachenkova, G. & Rempel, L. 1958. *Vydayushchiyesya pamyatniki arkhitektury*. Tashkent.

Reuther, O. 1912. *Ocheïdir*. Leipzig: J.C. Hinrichs Ed.

Reuther, O. 1938a. Parthian Architecture: A History. Pp. 411-44 In *A Survey of Persian Art I*, edited by A.U.Pope. London and New York: Oxford University Press.

Reuther, O. 1938b. Sassanian Architecture: A History. Pp. 411–44 in *A Survey of Persian Art I*, edited by A.U.Pope. London and New York: Oxford University Press.

Robertson, D.S. 1985. *Arquitectura Griega y Romana*. Madrid: Cátedra Ed.

Urice S.K. 1987. *Qasr Kharana in the Transjordan*. American Schools of Oriental Research, Durham, N.C.

Viollet le-Duc, E. 1858-68. *Dictionnaire raisoné de l'architecture francaise du XI au XVI Siècle*. 10 vols. Paris.