

Umayyad Arches, Vaults & Domes: Merging and Re-creation. Contributions to Early Islamic Construction History

Ignacio Arce

INTRODUCTION

Umayyad architecture and construction techniques are, up to a point, the result of a successful eclectic merging of Late Roman traditions and Partho-Sassanian ones, due to the need to establish new cities in the conquered territories and to create a new “aulic” imagery and an appropriate architectural framework for the new power. The seizing of key areas of the Byzantine empire (Syria, Egypt) and the whole of the Sassanian one (Mesopotamia, Persia and Central Asia), provided the new rulers with two endless sources of construction traditions, artisans and materials, that blended, and gave birth to new and idiosyncratic one.

This merging process between eastern and western traditions, started much earlier, but gained momentum during two key periods that correspond to the disappearance of the Levant border between East and West that took place, respectively, under the rule of Alexander the Great and that of the Umayyads.

The case of the structural roofing systems is a good example of this merging process that later became true hybridisation, with the translation of shapes and techniques into new building materials and *vice-versa*. Considered as a whole, they represent one of the most remarkable stages of technical development in the key transitional period from Late Antiquity to Early Medieval ages. For a general overview see Arce, 2006 [in press].

DIAPHRAGM ARCHES, RIBBED CROSS CEILINGS AND VAULTS. NEW ARCH TYPOLOGIES.

Diaphragm arches

A diaphragm arch consists of a self-standing arch placed transversally in a room, in order to reduce the span of the room ceiling. The resulting sections can be covered by a lintelled ceiling made of wooden or stone beams, trusses, or alternatively with barrel vaults resting on the arch and the perimetral walls.

The widespread use of diaphragm arches with lintelled ceilings during the Nabatean and the Classical periods in the Levant (Syria and Palestine), and in particular in the Hawran region (S of

Syria), is possibly the result of an early Parthian import. This system has been since then systematically used in the region in cisterns and dwellings, especially if the span exceeded 5 m.

Contrastingly, the solution using barrel vaults resting on the diaphragm arches, was probably introduced into the Levant from Persia by the Umayyads as no earlier samples of this variation exist in the region, while it is already present in the earliest Parthian samples at Ashur (**fig. 1a**) and at the Taq-i-iwan in Khark (Khuzistan), and at Sarvistan (Bier 1986, fig.87). The earliest (first decade of the 8th C.AD), and most outstanding samples of this solution in Umayyad period are found at Qasr Harane (Jordan), where almost all the rooms are covered using this system (Urice 1987). All the arches spring from a triple offset of prefabricated gypsum moldings that are cast separately on a piece of cloth (the prints of the fabric can be traced on the back), and then applied to the walls. This prefabricated moldings is composed of vertical sawtooth moulding between two fillets, being the pattern and the technique used, of clear Sassanian origin.

There have been identified two building phases that use slightly different techniques:

In the first one (**fig.1c**), the diaphragm arches are built with coarse-cut thin limestone slabs, and the barrel vaults resting on them are quite shallow (they are built with the same material in the fashion of the pitched-brick vaults). In the springers of the arch, the slabs corbel out at an increasingly greater angle, being build without centering. At the apex of the arch shoulders, the slabs are placed transversally, spanning the remaining central section of the arch. The gypsum-based mortar guarantees the quick bond between the slabs required for its construction. A similar technique is found in the relieving arches over the doors of this first phase, recalling samples from Persia (i.e. those from the Sassanian palace at Firuzabad –*Dieulafoyl884-: L’Art antique de la Perse*, quoted in Creswell 1969, fig.103).

In the second one (**fig.2a**), the central section of the arches are composed by rounded blocks of white limestone laid haphazardly on a thick bed of mortar. Both mortar and stones are comprised by two lateral pre-cast gypsum ribs that work as a formwork and temporal centering that is left embedded in the arch afterwards. Pre-cast gypsum structural elements, such as these ribs, are purely Sassanian in origin. They can be found also at Amman citadel palace (Arce 2001a & 2003a), at Sarvistan (Bier 1986, fig.80), and at Ukhaidir (with brickwork, Reuther 1939b, fig.130 -**fig.2c-**). At Harana they were also used for the construction of the small windows freezes over the entrances to rooms corresponding to this 2nd phase. The barrel vaults corresponding to this phase are higher in section (almost semicircular).

This system using barrel vaults over diaphragm arches, can be found in many other Umayyad buildings, like the audience halls from the baths at Qusayr Amra (**figs. 1b&d**) and Hammam as-Sarraj. In these cases the diaphragm arches are built with a technique demanding apparently a full-span centering, but with a low springing line.

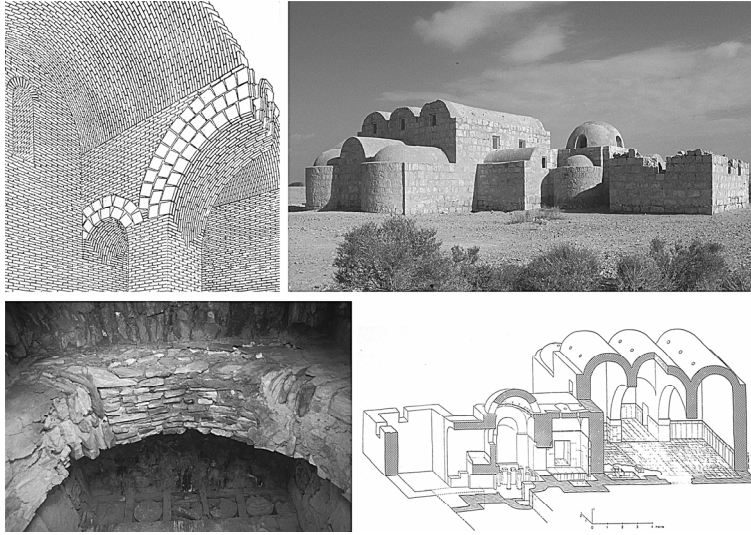


Figure 1. Diaphragm arches with barrel vaults. a : Ashur Palace (Reuther 1939a); b: Qusayr 'Amra; c: Harane, 1st phase technique: Notice the pitched slabs of the arch central section; d: 'Amra, section (Almagro et alli 1975).

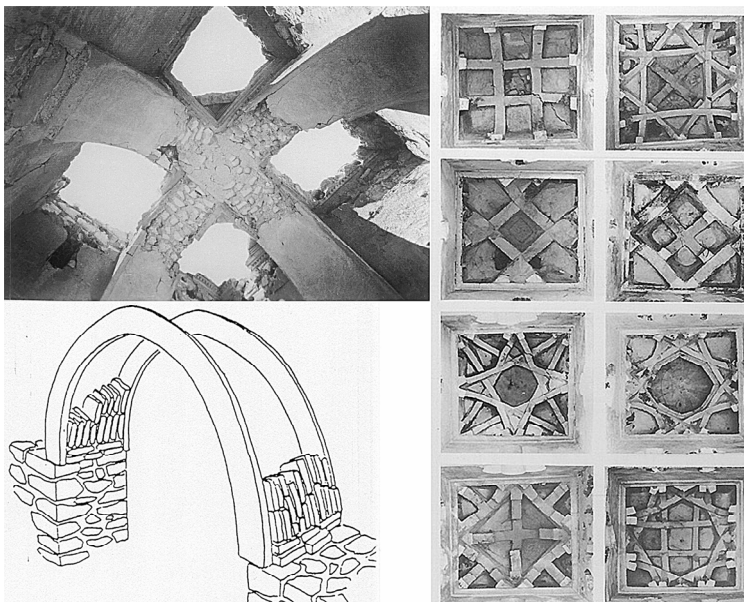


Figure 2. Cross ribbed vaults. a: Harane, cross ribbed ceiling built with 2nd phase technique: Notice the lateral pre-cast ribs of each arch (Urice 1987); b: Bab al Mardun mosque Toledo, ribbed vaults; c: Ukhaidir, arch with gypsum pre-cast ribs (Reuther 1912).

The setting and display of the diaphragm arches become increasingly complex, as arches can be multiplied and placed in parallel rows, defining regular subspaces or bays, each of them covered independently. This is for example the case of the prayer halls at Damascus, Cordoba and Hallabat mosques. In the first two cases the bays are covered by wooden trusses, meanwhile in the last one barrel vaults are used.

At Hallabat the mosque vaults are built with a concrete made with lime and volcanic tuff of clear Roman tradition (similar samples can be found at the Roman baths from Bosra and Shahba - Philippiopolis-). This light concrete vaults spring from a first course of voussoirs in limestone masonry, being the vault divided in sections by means of transversal arches embedded in the thickness of the vault (placed in correspondence with the position of the columns of the porticoes that support the whole). These embedded arches are indented with voussoirs of two different dimensions and with a trapezoidal section, so as to improve the link between the concrete and the arches. These arches were devised certainly to built the vaults in separate sections on movable and re-usable centerings that would rest on the corbelled molding that runs under the springers of the vaults. It is interesting to see how the same “design concept” can give birth to two very different architectural results (at Harane and Hallabat respectively) depending on the building techniques and materials used.

Ribbed cross ceilings

A further development was the perpendicular crossing of two arches spanning a square room, thus creating the first cross-ribbed ceiling. The first application of this innovative system is located in room 61 at Qasr Harane (**fig.2a**) The building technique correspond to the one from the 2nd phase described above, i.e.: using the pre-cast lateral ribs. The four bays created by the two crossed arches were covered by coffers with a pattern of inscribed squares rotated 45°.

Later, as in the mosques of Cordoba and Bab el-Mardún at Toledo (9th-10th C.AD), the intersecting arches were duplicated, so that the ceiling became divided into nine squares or oblong sections. The most sophisticated application entailed the ‘fractal’ repetition of a secondary series of interlaced arches, covering the square sections defined by the first series (**fig. 2b**). These pairs of arches could be rotated diagonally to the walls. Combinations led to increasing sophistication: eight arches, arranged into four pairs (two parallel and two rotated diagonally to the walls), would define an eight pointed star in plan. The remaining sections of the ceilings at Cordoba and Toledo were not covered by lintelled coffers, as in the earlier examples from Harane, but by true sections of vaults, thus creating the first ribbed vaults. Much latter this concept would be reproduced both in the mausoleum of Sultan Sanjar at Merv and in Gothic architecture (Arce 2003a).

Poly-lobed, pointed and ‘horseshoe’ arches.

The poly-lobed arch is a singular and very characteristic element of Islamic architecture. It has been questioned whether ‘Spanish’ Umayyad builders ‘transformed oriental decorative shapes into forms of construction, when in most instances, the evolution runs in the opposite direction’ (Ettinghausen and Grabar 1994, p. 137). This assertion is based on the belief that this element initially appeared in the mosques of Al Andalus (Cordoba and Bab al-Mardún), while in fact, the first examples are found in the Early Umayyad mosque at Hallabat in Transjordan (Similarly to the above described case of the first ribbed vaults from these same mosques, that have also an earlier antecedent in Bilad al-Sham, at Qasr Harane). At Hallabat, these very first poly-lobed arches were situated in the relieving arches above the doors. It is interesting to note that in this tiny mosque the Umayyad builders experimented with two possibilities: hollow or concave lobes and protruding or convex ones. In the first case – which would come to prevail–, the lobe is carved away in correspondence with the joint between two voussoirs, while in the second, each protruding lobe is fully carved in the intrados of every single voussoir. Both are clever and clear translations of a decorative feature into a structural element.

The pointed arch, used both in arches and vaults, is an equally distinctive feature of early Islamic architecture. The arch from the Justinianic church at Qasr ibn-Wardan has been proposed as its earliest antecedent, but this seems rather to have been the result of inadequate centering or other construction difficulties. The first true pointed arches were built during the Umayyad period. The offset of the centres of these arches could vary from one-tenth of the span (at Amman, Qasr Tuba and Mshatta), to one-seventh or one-eighth (at Khirbat al-Mafjar).

The origin of the horseshoe arch is rather controversial, since it was developed almost simultaneously in different areas; in Umayyad architecture there seem to have been both Sassanian-origin horseshoe arches on decorative plaster or stone friezes (Harane, Amman, Qastal), and stone-masonry built ones from the Byzantine world (Mafjar and Amman). Antecedents of the latter can be traced in Byzantine Syrian churches like that of Bizzos (6th C.AD).

Reduced-span centerings and projecting voussoirs

In many of the masonry and brick-built arches, the actual arch began at a higher level than the formal springing line, since the construction of the first voussoirs, in many cases horizontally projecting courses, didn’t require centering. Therefore, the actual span that had to be crossed with a centering was reduced to up 2/3 of the original. In many cases, this was combined with voussoirs projecting inwards and outwards (i.e., towards the intrados and towards the extrados of the arch) to offer support to span-reduced centerings. The inward projection was usually carved away afterwards (Arce 2003a). This procedure had been widespread since the Roman period and several antecedents can be found, e.g., in the Roman temple at Atil in the Hawran (2nd C.AD –**figs.3c&d**),

or in the baths at Shahba-Philippopolis (3rd C.AD). Other samples from Justinianic period are found at Resafa (Sergiopolis) and Halabiye.

This crafty solution can be applied for semi-dome construction as well (i.e. at the Roman Baths and the Byzantine Cathedral at Bosra). At the entrance hall from the Amman citadel palace is found the most outstanding sample of this system in an Umayyad Building (**fig.3a&b**): there, it was used in the construction of the transversal arches that support the central dome, and in the lateral semi-domes (Arce 2003a). Some similarities in the procedure of construction of these arches and lateral semi-domes can be found at S. Sophia (**fig.3e**). Although S. Sophia was built in brick and the semi-domes rest on a semicircular plan (avoiding thus the transitional troubles, Choisy 1883-1997, fig.81), we can trace the common idea of reducing the span of the semi-dome by building a projecting section of it without the help of a centering, meanwhile the remaining section (“C” in Choisy’s sketch) is built leaning against the thick transversal arch (“T”) with reduced span centerings resting probably on that same arch and the step devised on the already built section (“H” in Choisy scheme).

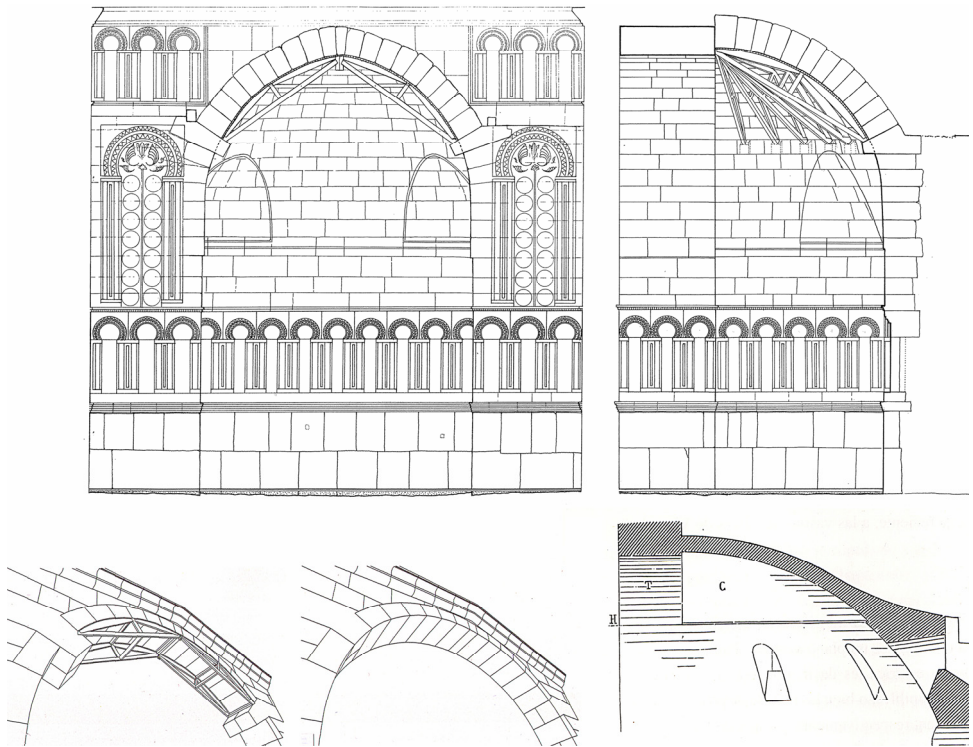


Figure 3 Projecting voussoirs and reduced span centerings. a&b: Amman citadel entrance hall. (notice the false squinches); 3c&d: Attil (S. Syria) Roman temple; e: Constantinople, S.Sophia (Choisy1883).

VAULTS

PERSIAN & MESOPOTAMIAN TRADITION VAULTS

Brick barrel vaults built without centering (or “Pitched-Brick vaults”)

Brick masonry and its most relevant structural achievement, the barrel-vaults built without centering are the most significant Mesopotamian contributions to the ancient building technology (the oldest brick vault of this kind, found at Tell al-Rimah in N. Iraq, is dated c.2100BC! –Oates, 1996, fig.28-). They had already been adapted in Egyptian structures from the New Kingdom, like the Ramesseum granaries. These vaults consist of rings of vertically laid bricks leaning slightly, the first ones against the end wall of the room to be roofed and afterwards resting against the previously laid rings (**figs.4a&e**). This leaning became increasingly bigger when the system was adopted by the Byzantines, who gave birth a very characteristic system of brick vaulting (Choisy 1997).

The unusual vertical arrangement of the bricks was made possible as they were held together with quick-setting gypsum mortar; it became thus possible to cover large-span rooms in a short time. The span could be reduced by using overhanging horizontal brick layers, following the vault profile, and even offering an offset marking the false springing-line of the vault. This solution that is found in the Sassanian model at Ctesiphon, was adopted by the Umayyads for the vaults from Qasr al-Hayr as-Sharqi (**figs.4d&g**) and for those at the unfinished palaces of Mshatta (**figs.4b&e**) and Qasr Tuba (**fig. 4c**). They had, respectively, parabolic (at Ctesiphon), semicircular (Qasr al-Hayr), and pointed arch sections. All the Umayyad brick vaults are just found in structures built after the 2nd quarter of the 8th C.AD., and are closer to the original Persian technique than to the “modified” Byzantine one, because of the completely vertical display of the bricks and the thinner mortar joints (smaller than the brick thickness), the opposite of the Byzantine technique (found for instance at *pretorium* from Qasr ibn-Wardan, in N. Syria -**fig.4f**).

At Qasr al-Hayr as-Sharqi the hybridisation with “Byzantine” techniques however is evident as for the combination with stone springing voussoirs (**figs.4g**), or the setting of secondary rows of “standard-laid” brick vaults over the pitched ones.

Laying bricks on their edge is one of the strangest but most defining features of ancient Mesopotamian and Parthian architecture (**fig.1a**). This unusual method, which was passed on to the Sassanians and the Umayyads, can easily be explained for arches and vaults (due to the described building process without centering), but not when it was employed in walls or pillars, as it does not help the stability of the concerned element. Examples can be found in the latest phases of the Kassite palace and ziggurat at Dur-Kurigalzu, near Baghdad, 12th C.BC (Oates 1996, fig.67); at the Parthian palace in Ashur (Reuther 1939b, fig.99,a&b &100); or in the piers from the Tarik Khana mosque at Damghan in NE Iran, 9th C.AD (Creswell 1989, fig164).

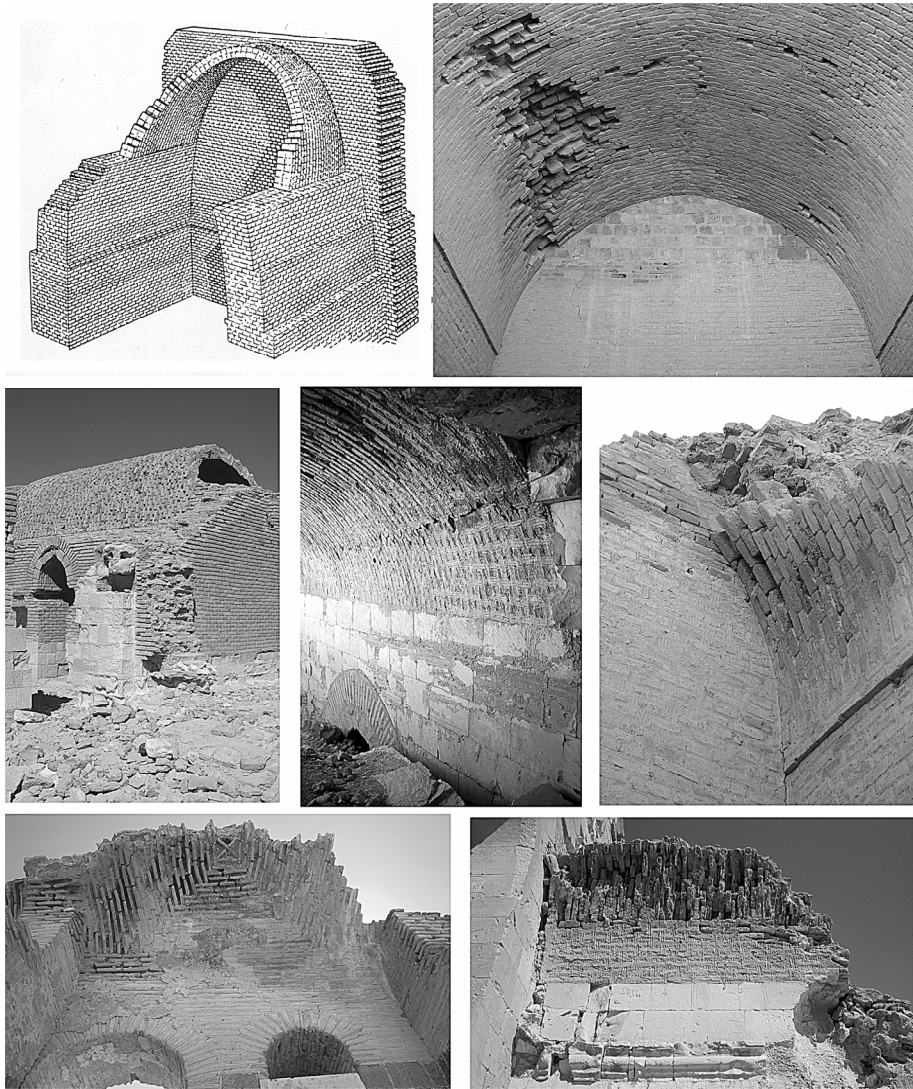


Figure 4. Pitched-brick barrel vaults. a: Sassanian model (Reuther 1939b); b&e: Mshatta (note the pointed section and the bricks leaning against the end wall); c: Qasr Tuba; d&g: Qasral Hayr as-Sharqi (notice the Sassanian “basketry treatment” of the joints); f: “Byzantine” pitched-brick vault from Qasr ibn-Wardan.

‘Pitched-stone-slabs’ vaults

At Qasr Harane we found the transposition of this building technique into stone by using thin slabs instead of bricks. Due to its rough cut the result is logically less regular and neat, thus the rows lean

more against the end walls. The remaining central void is usually filled with the same system but placing the rows transversally.

“Pitched-brick cloister vaults” or “*Quadripartite lanceolate vaults*”

This characteristic vault is found in the Khorassan area (specially around Merv), and is the result of the intersection of two pitched-brick barrel vaults to form a ‘cloister vault’ (Herrmann 1999, p.57 & figs. 51, 52, 112; Arce2003, fig.22). Usually is reinforced with vertical protruding ‘ribs’. Its use seems to be restricted to this geographic area.

Squinch vaults

The squinch vault is a very idiosyncratic Central Asian vault, that also shares the same structural and technical concepts of the Sassanian pitched-brick vaults. This sort of vault is also known as ‘*khorrassani*’ due to the geographical area where it is more commonly found (NE Iran), or even “*balkhi*” in reference to the city of Balkh (present day Mazar-i Sharif, Afghanistan).

The construction process starts with a small arched course laid in each corner of a square room, advancing with new and increasingly larger arches leaning on the previous ones, defining thus four corner half-cones that meet in the centre of each side of the room (**figs.5a&c**). The remaining square opening could be covered by continuing in the same way, as is done still nowadays in Khorassan, or by re-starting the process from the newly created corners. (**figs.5b&d**).

Squinch vaults were apparently hardly ever used in early Islamic monumental structures, as no samples from this period have survived. The only surviving vaults are later: in the east we have those from Khorassan (Iran and neighbouring Turkmenistan & Afghanistan) houses (i.e. those from Merv -**fig.5a-**), and from the congregational mosque at Isfahan (the vaults are from the 10th C.A.D. onwards); in the west, the vault of the ‘Cuba’ (from the arabic *Qubba* or dome) of S. Domenico near Castiglione in Sicily (**fig.5b&d**), that is tentatively dated between the 11th and the 12th c. A.D. (Copani & Buonanno, 2003). In this case, the squinches are set on arches giving birth to a hybrid figure, almost spherical, that could be called “squinched spheric vault”, found also at the S.Demetrius tomb at Salónica (**fig.5h**).

Stepped squinches domes

Stepped squinches domes like the famous one from Diocletian’s Palace at Spalato and from S. Demetrius tomb at Salonica (**fig.5f**) are clearly related to this concept of squinch-vaults from Persian origin. In these cases the conoidal squinches do not need anymore to span the corner of a square room but small sections of an already circular plan, becoming thus almost a true spherical surface. The decorative effect of this solution, similar to a scale-pattern, would gain a decorative

value by itself (pointed by Choisy see below). This could have been the source of the purely decorative pattern that we find carved on the domical voussoirs of one of the domes (or spherical vaults) from Qastal (**fig.5g**). This ‘scale-pattern’ is a popular Hellenistic motif adopted very early by Parthians and Sassanians and reintroduced in Umayyad period as an *endless* or *infinite* decorative pattern used extensively at Amman Citadel and Qastal.

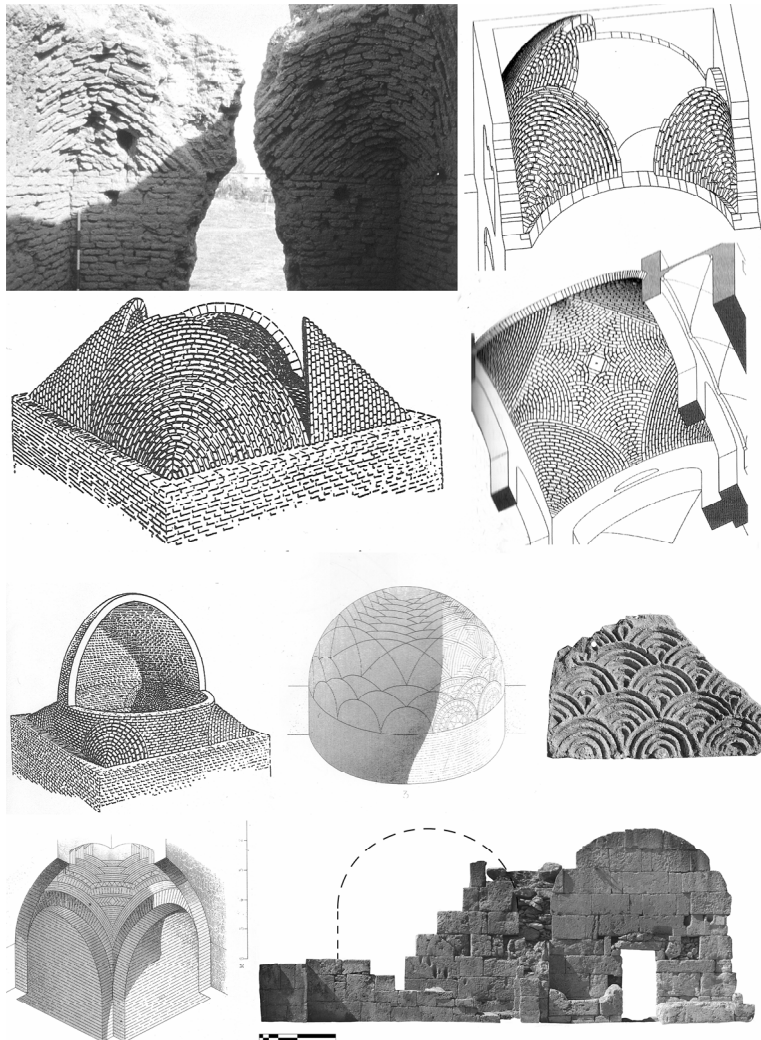


Figure 5. Squinches. a: Merv, squinch vault (Herrmann 1999); b&d: Castiglione, *Qubba* “squinched spheric vault”, (Copani & Buonanno2003); c: Squinch vault (Reuther 1939b); e: dome on squinches (Reuther 1939b); f&h: Salonica, S. Demetrius, “Stepped squinches dome” and “squinched spheric vault”(Choisy 1883); g&i: Qastal, domical voussoir with ‘squinches’ or ‘scales’ pattern and springers of spheric vaults.

Choisy presents (1997, fig.91) a semi-dome from the Byzantine ruins at Ephesus, belonging to a fountain (no date is provided). The pattern of the courses corresponds actually to a stepped squinch vault, although is dismissed by Choisy who says that “the art of construction has nothing to do with these fantasies. In this case the building pattern is just an excuse for the decorative one” (Choisy 1997, p. 80). The elegant decorative aim and results of this technique cannot be denied, as (like in the sample from Castiglione) the builders themselves used two different coloured materials in alternating courses to enhance the building pattern. But this do not diminish the technical value of this constructional achievement, on the contrary, shows the expressive value of a building technique by itself that in many cases will gave birth, later, to a purely decorative pattern without any tectonic or structural value. This is the case of the so called ‘*ablaq*’ or alternating courses of contrasting colours used in wall masonry or arch construction (very popular specially in Mamluke and Ottoman periods): it has a clear origin in the alternating use of different materials with different and characteristic constructive aims, becoming later a mere decorative fashion.

“BYZANTINE” OR “LATE ROMAN” TRADITION VAULTS.

It must be stressed again that the technical hybridisation of Roman and Persian techniques started much earlier, for instance with the adoption by the Byzantine masons of the pitched brick-vaults. They developed the concept, becoming true masters of it (Choisy 1997) using transversal arches to divide big areas to be covered into small sections, that were filled up with an improved version of the old Mesopotamian method. Samples of this can be seen in the Byzantine cistern at Aleppo citadel or at Qasr ibn-Wardan (**fig.4f**). The main differences with the Persian vaults are the mentioned greater thickness of the mortar joints, and the not occurrence of totally vertical rows of brick arches in the pitched-brick vaults.

Brick barrel vaults using the “Byzantine” technique are not found in Umayyad buildings, but mixed brick and stone masonry of Byzantine tradition occur in some Umayyad buildings: At Khirbat al Mafjar there are examples of cross vaults and domes on pendentives built in this mixed brick-stone masonry (Hamilton 1959, figs.36-41), and further samples can be seen at Qasr el-Hayr as-Sharqi (**figs.4d&g; 6b&c**). Other mixed techniques using volcanic tuff, also of late Roman tradition have been already described from Hallabat.

Full-stone masonry barrel vaults of ‘Late Roman’ tradition were used as well, for instance at Muwaqqar, Qastal and Amman Citadel, introducing in the last one a pointed arch section.

Groin (or cross) vaults & Sail (or spherical) vaults.

These sorts of vaults achieved their perfection in late antique Syria both in stone masonry, and brickwork. Regarding groin vaults, in the theatre at Shahba –Philippopolis- (3rd C.AD) can be found an early sample in stone (with “elbow” voussoirs for the groins -**fig.7a-**), meanwhile samples in brick

can be traced at the *pretorium* of Qasr Ibn Wardan (SE of Aleppo), or in the Justinianic fortress of Halabiye (built in the Limes by the Euphrates).



Figure 6. Mixed Brick & Stone masonry of Byzantine tradition. a: Qasr Ibn Wardan, Justinianic *pretorium* using basalt, limestone & brick; Qasr al Hayr as-Sharqi. Domes on hollow towers, b: exterior; c: interior.

Groin or cross vaults in stone masonry were not used extensively in Umayyad period (probably due to its demanding technical requirements when built entirely in stone masonry, and their unwanted thrusts): Usually only the springers are carved in stone, using bricks or thin slabs for the rest of the vault (**fig.7d**). They are mainly used to cover small square rooms like the *tepidaria* of different baths like Qusayr ‘Amra (**fig.7c**), Hammam as-Sarraj, (**fig.7b**), and probably the ones from Amman citadel (Arce 2004) and Jabal Says (according to a ‘standardised’ design, in all these baths *frigidaria* were covered by barrel vaults, *tepidaria* by cross vaults, and *caldaria* by domes on pendentives). Only few remains indicate its use in the bath hall at Mafjar, Jerico (Hamilton 1959, Pl.CV, & figs.35&36), as these vaults collapsed long time ago and their shapes were elicited from the remains of their springers. At the guard room of the outer hydraulic enclosure of Qasr al-Hayr as-Sharqi there is a further isolated sample of Umayyad brick cross vault (Creswell 1989, p. 161).

Sail, or spherical vaults can be understood as a particular case of cross vaults with semicircular groins (the diagonal intersecting arches) and thus an apex higher than the crown of the main lateral - transverse- arches (otherwise they can be seen as the basic feature for achieving true spherical pendentives). The very first cases date from Roman period (2nd C.AD): the tomb known as Qasr Nuwayjs (at Amman) and the *Caldarium* from the baths at Jerash (**fig.8a**). In the theatre at Shahba there is an outstanding sample that we will describe below (**fig.8b**). Sail vaults from Justinianic period built in brick occur at Halabiye, and Qasr ibn-Wardan (**fig.8c**), and in stone masonry we

have the so-called “Golden Gate” (**fig.8d**) at the *Haram as-Sharif* complex in Jerusalem (Creswell 1969: 463), where exists a solution of twin shallow spherical vaults formed by the penetration of a form that is less than a sphere, and two domes on shallow pendentives (probably built in the 7thC.AD under Modestus). These spherical vaults served as a model to the new ceiling of the (originally Herodian) ‘Double Gate’ (Choisy 1997: Lam.XV.2). Its new ceiling must have been built before the Al-Aqsa mosque, just above it, something that leads de Vogüé and Creswell to date it also in Byzantine period (Creswell 1969, p. 465). But taking into account the excavations carried out in the area in the 70’s (Ben Dov 1971&1982), that uncovered the Umayyad palatine complex at the feet of the S. side of the *Haram as-Sharif*, and demonstrated that this door and the ramp connected the palace with the mosque by means of a newly built bridge, we can raise the hypothesis that these vaults could have been set when the palace, the mosque and the bridge were built.

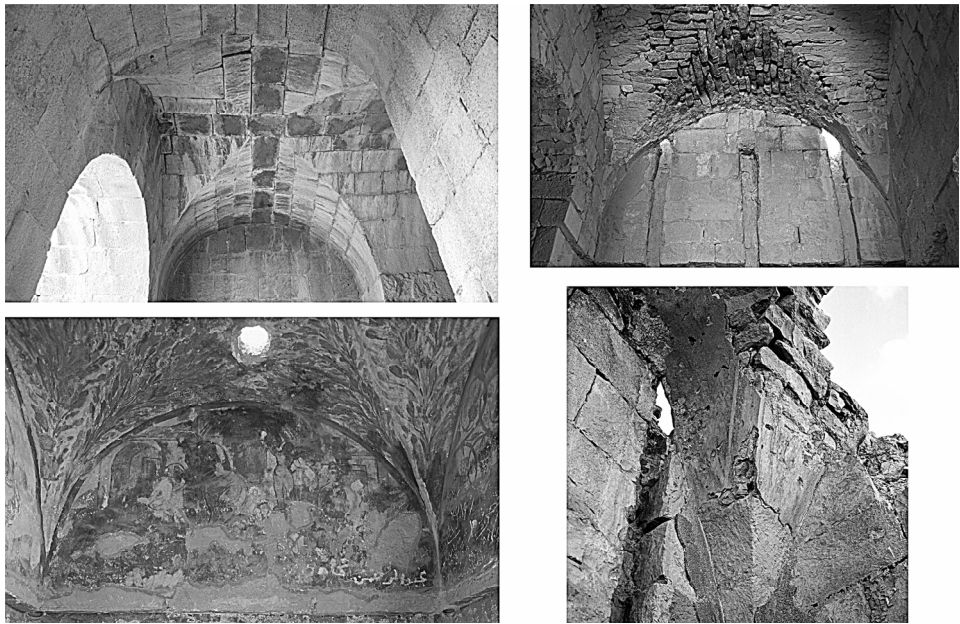


Figure 7. Cross (groined) vaults. a: Shahba Roman theater; b&d: Hammam as-Sarraj, detail of the stone springers; c: Qusayr 'Amra.

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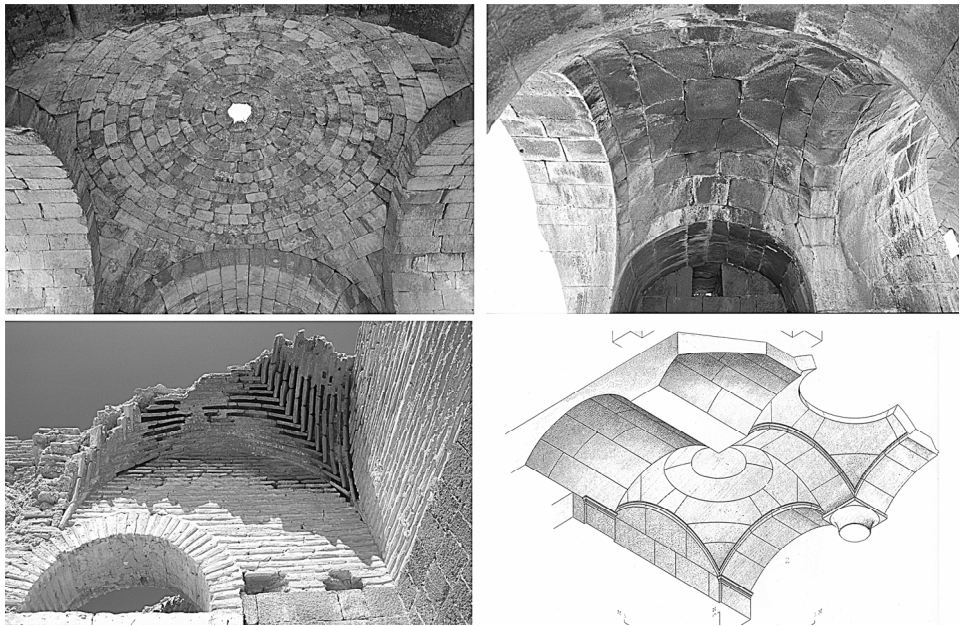


Figure 8. Sail (spherical) vaults. a: Jerash, Roman baths (spherical conical joints); b: Shabha Roman theater (square in plan joints), notice the perimetral domical voussoirs; c: Qasr ibn-Wardan church, brick vault (notice the thick mortar joints); d: Jerusalem, ‘Double Gate’ (Choisy 1883: Lam.XV.2).

No samples of true sail vaults from Umayyad period have arrived to us, but we have some hints to put forward their hypothetical existence: This is the case of Qastal entrance Hall: the lower floor of the entrance hall was reconstructed by Carlier & Morin with a double dome *on squinches*, that do not fit with the built context (1984, figs.46, 54, 55, 59& 62); As a preliminary outcome of the ongoing research on this issue, we can put forward the hypothesis that this space (**fig.5i**) was covered with twin spherical vaults (or alternatively -although less convincingly- with twin groin

vaults) due to technical and symbolic reasons. Firstly because otherwise the upper floor level would have been too high, and secondly, because it makes no sense to use a dome both, over the throne room in the upper floor, and also covering the entrance corridor (just below it). The preference for the former hypothesis is based in the lesser thrusts exerted at the base, and the better structural performance (taking into account the existence of a domed hall in the upper floor), and supported on the material evidence provided by the domical voussoirs (**fig.5g**) from different spherical domes/vaults retrieved. The latter possibility (groin vaults) would allow an even lower floor level for the upper section of the building.

DOMES, SQUINCHES AND PENDENTIVES

The blending of the two cultural models merged by the Umayyads also has a relevant expression when dealing with structural systems to support a dome on a square room as is the case in the use of both squinches (an originally Iranian invention) and pendentives (the most outstanding achievement of Syrian-Roman stonecutters), and the way domes were actually built. Domes were made in various shapes—e.g., hemispheric or ‘umbrella’ domes—and could be executed in a range of materials, such as limestone, shale (e.g., the disappeared one at Hammam as Sarraj), volcanic tuff (e.g., at Hallabat) or, like the Dome of the Rock, in timber.

Domes were usually used on top of audience, throne halls (Amman, Kufa, Qastal, Harane, etc), or important religious shrines (Jerusalem) according to a symbolic value of this element; but also to roof the *caldarium* of a bath building (‘Amra, Sarraj, or Anjar, using respectively unhewn stone, shale, and brickwork); to cover porches from palaces and mosques (as at Mafjar and Hallabat –both on pendentives, but built respectively with brickwork and ashlar masonry-), pavilion fountains (*sabil*), at Mafjar (in brickwork) or even topping round hollow towers (as those from Qasr al-Hayr as-Sharqi -using also brickwork-)

Domes on Squinches

The Sassanian-origin domes on squinches can be seen as a particular case of the squinch vault described above: In this case the four corner half-cones (or half-*conoids*, if its profile is a parabolic one) are not carried to the middle of the room, leaving some space between them that is filled with horizontal courses, until a horizontal circle is made at the crown of the squinch arches, on which the dome will rest. The dome has a half-elliptical section and is built with horizontal circular courses, without using centering, by means of gypsum mortar (**fig.5e**). In the dome over squinches in the “Sassanian palace” at Sarvistan, Iran (L. Bier [support an Islamic date for this building], 1986), the transition section, formed by the drum with the squinches, is made of cobbles and roughly cut stones embedded in gypsum mortar (as are most of the building’s walls), but the dome itself is built with bricks. Meanwhile in the dome over squinches at the Ardashir’s Palace in Firuzabad (3rd C.AD), the squinches and the dome are both built with cobbles embedded in gypsum mortar.

At Qasr Harane three different samples of these squinches can be seen, using both shapes and techniques from the Sassanian tradition in an early Umayyad structure (first decades of the 7th c. AD, Urice 1987, p.33): The first two ones (**fig.9a**) are found at room #51, arranged in four couples in each corner of the room: The first one is devised as an arch placed diagonally in the corner of the room supporting a coffered ceiling that fills the residual triangular space; The second one is placed related to the previous one (together support the half-domes that exist at both ends of the room) and has the shape of a conoid (similar to the shape of the ones from Amman citadel entrance hall). It is much smaller and solves the awkward setting of the half-dome. The third one is found in room #59 and support the half-dome of the southernmost bay (**fig.9b**). They are built up of three concentric round arches that define three sections of half-cones displaced telescopically. In room #26 (the main hall over the entrance) there is a central square bay that probably was covered with a dome.

The adoption of a “Sassanian shape” (the dome on parabolic-conoidal squinches) at the entrance hall at Amman citadel (**figs. 3a&9c**) and the attempts to built it into stone with the means and know-how of the local stone-cutters of Byzantine tradition, is an extraordinary sample of the unexpected results obtained from this merging of techniques and shapes at a later stage (mid 7th c. AD). The translation into stone of shapes with no possible stereometric solution posed to those experienced stonecutters a real challenge that nonetheless was solved in a crafty way: The shape of these squinches was carved, or rather sculpted, out of a series of overhanging horizontal stone courses. These horizontal courses reach the level of the crown of the squinches, that corresponds to that of the semi-circumference on which rests the corresponding semi-dome. From that level the semi-dome is carried out in the “standard” Byzantine way of building a dome with stone, i.e.: using spherical radial joints (Arce 2003a).

Domes on ‘Lintelled squinches’.

A singular case of *lintelled squinches* was recently discovered by the author, at the Amman citadel Umayyad palace, supporting the dome over the throne hall. This *unicum* is another sample of translation into stone of a Partho-Sassanian shape, originally conceived, in this case, in timber (Arce 2000).

This element was composed of several stone-cut elements (**fig. 10**): Firstly the ones forming the “beam” or squinch lintel itself, originally a timber beam that, translated into stone by Syrian stonecutters, becomes a three-piece “flat arch”. It is composed of two lateral corbelled pieces embedded diagonally into the wall corners, and a “key stone” that fits between the two corbels with a joggled joint (compare it with the late antique three-piece flat lintels from Hallabat –Arce 2005). These elements, due to their wooden origin, were decorated with a semicircular molding in their lower section and with a couple of rolling corbels (*‘modillones de rollos’*) in the areas close to the wall. In their back face they present a recess to support the coffered triangular slab that serves as a ceiling for the space spanned by this composite lintel. The coffer recalls the solution of the arched

squinch from room #51 at Harana, and also the Parthian antecedents of the system. Traces of the stone carved cornice, recalling also a Sassanian pattern of teardrops, that was placed at the base of the dome was retrieved from the site as well.

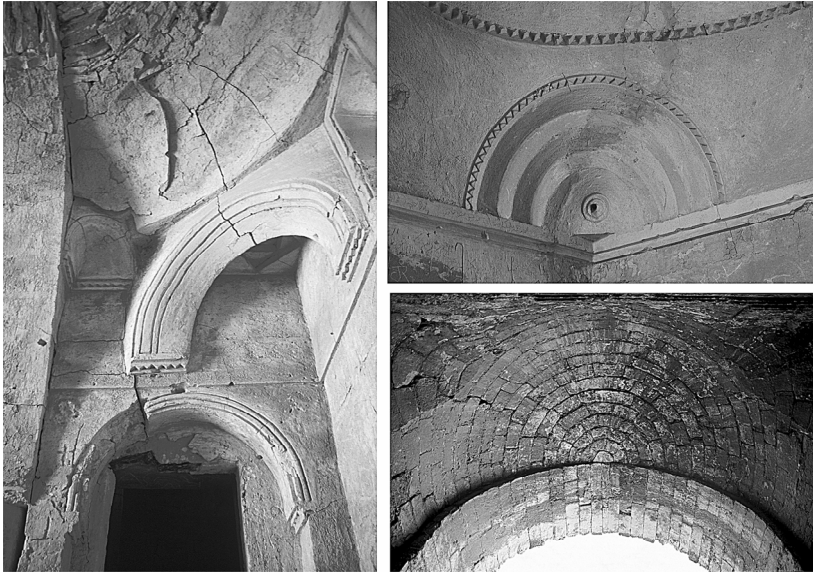


Figure 9. Domes on Squinches. a: Qasr Harana room #51; b: Qasr Harana room #59; c: Amman citadel, false 'sculpted' squinches.

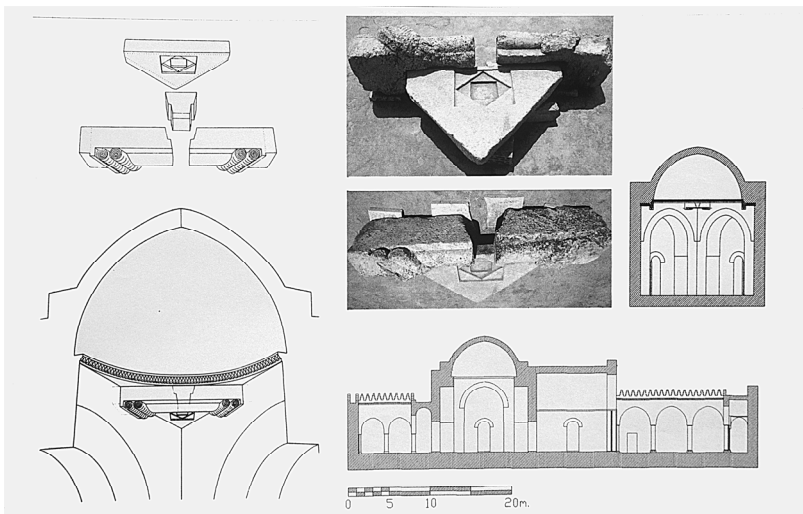


Fig. 10. Domes on Lintelled Squinches. Amman Citadel Throne hall (Arce 2000).

Most probably, the dome on top of this squinches was built with a Sassanian technique using cobbles embedded in gypsum-based mortar, and with a slightly parabolic section. This hypothesis relies on the fact that no traces of stone voussoirs, nor bricks, have been found on the spot (Olavarri 1985), meanwhile almost half of the pieces from the squinches have survived (allowing this reconstruction)

Antecedents of this element can be traced in the Parthian Palace at Nisa, being still nowadays a standard roofing system in the North of Iran and the neighbouring regions as Azerbaijan, Georgia, Armenia and Tajikistan (Arce 2000). It somehow follows the same principle of the squinch vault, but in this case instead of arches, we have horizontal beams placed diagonally that define in plan a series of squares inscribed in each other and rotated 45° regarding the previous ones. This principle is also the origin of the decorative coffered feature usually found in the horizontal spandrels, or ceilings, that cover the area spanned by the squinch.

The dome from Sana'a Mosque and the *lintelled squinches*

When re-assessing the descriptions of the Sana'a Mosque, we realise that the "dome" in front of the *mihrab* was actually built using this Parthian-origin feature:

The ceiling in front of the *mihrab* and to the west of it is composed of a large corbelled 'flat dome' or 'lantern', flanked on either sides by a pair of smaller flat 'domes'. On close examination the corbelling is seen to be made of large flat pieces of wood resting on beams, while the flat circular 'dome' or 'lantern' in the centre is of ancient alabaster, long since turned black and thickly plastered over on the outside, but originally doubtless translucent so that the light poured in on the centre of the *quiblah* wall. Two further beams were introduced at some subsequent date to help support the central 'dome', *disguising the original appearance which was of a square placed diagonally in a square formed by beams, quiblah and arcade wall, from which the corbelling rose up...* (Serjeant & Lewcock, 1983).

This could be the result of the close influence of Sassanian culture during pre-Islamic and Umayyad periods in Yemen, that is reflected in the general plan of the building as well, that corresponds to the so-called "Iranian type" (that recalls Persian apadanas).

Domes on Pendentives

The pendentives can be seen as the most important outcome of the late Roman tradition of carved stone masonry (Creswell 1969, pp. 450-471). As we have seen the first samples of spherical vaults and true pendentives were actually built in Roman Syria (Nuwayjs, Jerash, Shahba). The high level of excellence reached by Syro-Byzantine stonecutters was developed and improved even further

during the Umayyad period, as can be seen in the following examples of domes on pendentives. They allow us to affirm that (similarly to the development of Sassanian techniques that we have presented), late Roman stereotomy reached its splendour in Umayyad buildings.

The case from the *caldarium* at the baths of Hammam As-Sarraj (close to Qasr Halabat), represents a superb sample of the canonical ‘standard’ solution of a stereometric dome on pendentives (**fig.11a**): The perimetral arches have a slightly pointed section with a keystone narrower than the standard voussoirs, and the spherical triangles are built with courses circular in plan (both of precisely cut limestone masonry). Above it an “umbrella” dome with nineteen projecting ribs built with thin slabs of un-hewn shale (now collapsed) was built. It was pierced with small circular holes in its base (Bisheh 1989, pp. 229). The contrast with the building technique of the lower section was not noticeable originally as both sections were covered with painted plaster. The groin vault from the *tepidarium*, and the barrel vaults from the *frigidarium* and the furnace, were also built in the same fashion (probably due not to a shortage of economic resources but in order to achieve a lighter solution than the one of an ashlar masonry dome or vault).

But we can find proper pendentives built with other techniques: at Qusayr ‘Amra both the dome (hemispherical with four arched windows) and the pendentives, are built with thin roughly hewn slabs of limestone masonry (**fig.1b&d**). In this case, the geometric profile of the pendentives is not very accurate, being its surface originally covered with mosaics, meanwhile the dome was lined with mural paintings representing the sky constellations. In order to give an accurate geometrical profile, as well as a continuous and even support for the dome, a cornice of limestone was laid. Externally the vaults were protected with a double layer of lime mortar plaster, of which the final one was mixed with crushed bricks (as an hydraulic agent) and crushed flint stone. It is striking the similarity of the design of this building and the previous one, being the main difference the precise ashlar masonry used at Hammam As-Sarraj, due to the proximity to the quarries.

At Mafjar (Jerico), Hamilton found traces of several brick domes on pendentives in different rooms (all related to the aulic building of the “bath”, and all of them with a drum with pierced windows or blind niches): the *diwan* (**fig.11c**), the bath porch and the central bay of this same building.

The pendentives from the central bay of the bath hall, built in brick masonry on stone springers, represent a demonstration of high level of geometric knowledge achieved: in “normal” pendentives, the basic figure is a hemisphere intersected by four planes raising vertically from the sides of the square to be covered (inscribed in the circumference base of the sphere), thus creating vertical semicircular arches in the lateral cut sides of the hemisphere. The modified pendentives from Mafjar are an extraordinary geometrical *tour de force*, where the basic figure is less than a hemisphere and the four intersecting planes are the sides of a pyramid. Thus, the resulting arches are parabolic in shape and are not in a vertical plane but in an inclined one. This makes it necessary

to add sections of barrel vaults to reach the semicircular sides of the room so defined (Hamilton 1959, pp. 81 and fig.42).

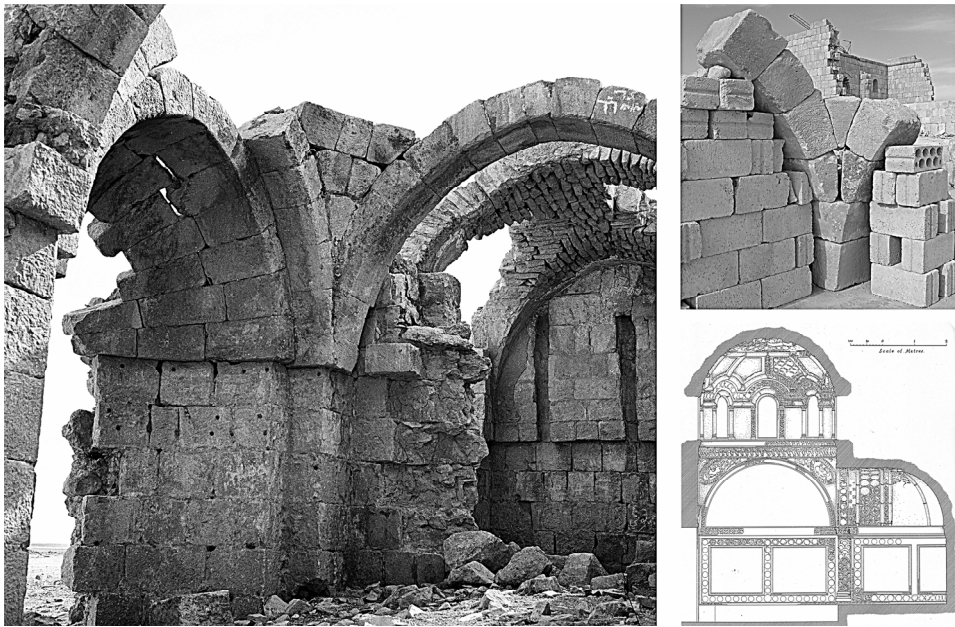


Figure 11. Domes on Pendentives. a: Hammam as-Sarraj, transversal arches separated from the pendentives; b: Hallabat, transversal arches integrated with the pendentives; c: Mafjar, dome on a pierced drum (Hamilton 1959).

The recently discovered elements of a dome on pendentives from the mosque at Hallabat constitutes a final example (discovered during the ongoing excavation and restoration project directed by the Author, and not yet published). This dome testifies to more formal constraint and technical proficiency: normally, the spherical triangles or pendentives are physically separated from and constructed after the four supporting lateral (transversal) arches. At Hallabat, the arch's voussoirs and the neighbouring sections of the pendentives were carved from the same block (**fig.11b**). This design would have led to a pattern of square joints in plan, but surprisingly, the remaining sections of the pendentives are carved with the “standard” spherical joints (circular in plan), that drive the thrusts directly to the corner pillars. The base of the dome was defined by a cornice with a three-step molding. The dome resting on these pendentives apparently is not a true dome with spherical radiating joint: the first three or four courses would have had horizontal joints, projecting horizontally outwards, being carved in the shape of a sphere. On top of them, the remaining section of the spherical surface would be achieved by means of a “light concrete” made of volcanic tuff and lime (exactly the same used in the barrel vaults of the interior of the mosque, described by Butler). This apparently contradiction between the high degree of stereometric sophistication achieved in the

pendentives and the (apparent) awkwardness of the dome, would have, once more, a mechanical explanation: as far as this dome on pendentives was devised as an external porch to the mosque, with little and not uniform buttressing against horizontal thrusts, these had to be reduced to a minimum to prevent its collapse. Building the dome in this way, guarantees that almost all the thrusts would be vertical, reducing the problems of stability. This may be also the explanation for the singular solution of the pendentives themselves (built partly as a section of the perimetral arches of its square bay), as the horizontal thrust of the pendentives would thus be reduced as well (as the true pendentives are reduced in size and weight significantly). This means that is a deliberate and crafty solution to a structural problem, not a lack of adequate know-how (the proof that these masons and stonecutters were able to built a proper masonry dome with spherical radial joints can be found in the semi-dome of the *mihrab* or in the even more complex solutions in the nearby and contemporary building of Hammam as-Sarraj –see below-).

Only a precedent of this solution has been found up to now. This is the case of a sail vault in basalt masonry from the Roman theatre -3rd C.AD- at Shahba (*Philippopolis*) in the Hawran (S. Syria), where the perimetral sections of the spherical vault were also carved together with the lateral arches that define the bay. Here the rest of the vault is achieved with joints parallel in plan to the sides of the vault bay (**fig.8b**). This solution may be determined by the fact that the vault itself is not square in plan but oblong (being more adequate and easy to disguise this fact if the joints are not planned according to an spherical pattern –circular in plan-).

Semidomes

We find these elements usually associated to very different architectural elements: mihrabs, and baths exedrae. The recently discovered semi-dome from the Hallabat mosque together with the one from Mafjar are probably the oldest samples retrieved that can be dated undoubtedly in Umayyad period (firstly introduced at Medina by Walid), allowing a precise study of this feature. The uniqueness of the sample from Hallabat is reinforced by its external appearance, as is the first *mihrab* (and the sole Umayyad one) built externally with a polygonal plan: its perimeter corresponds to seven sides of a polygon of fifteen ones (possesses a dihedral angle of 156°).

We find them also as the end of a barrel vaulted rooms (as in the alcoves flanking the throne recess from Qusayr ‘Amra (**fig.1b**), or Mafjar (**fig11.c**), or other vaulted reception rooms as the described above from Harana . The case from Amman reception hall, built on “false squinches” (above described -**figs.3a&9c**-) is particularly noteworthy.

Stone masonry semi-domes with “Fan radiated” joints

The “usual” way of building a semi-dome in stone masonry (with ‘conical’ joints –circular in plan- and radiating from the centre of the sphere) requires to built at least a quarter of a sphere (i.e. to be

at least semicircular in plan). If this is not the case, these conical joints create a series of thrusts perpendicular to the plane of the façade, that are not balanced nor neutralised, invalidating the equilibrium of the system. This alternative radial display of the joints transfer the thrust directly to both sides, preventing the sliding of the voussoirs towards the front. In this way, the reduction of the dome circumference in plan, does not affect its stability. Apart from the cases mentioned by Choisy (fig.12d), from the theatre at Jerash –Jordan-, and from the *pretoria* at Musmiye –Ledjah- and Sanamen, in the Hawran - S. of Syria- (Choisy 1997, pp.75-77) an outstanding antecedent has been identified at the Roman Baths from Shahaba (*Philipópolis*) dated in the 3rd C.A.D. (Fig.12a).

At Mafjar and Hammam As-Sarraj (fig.12b), we have Umayyad samples of semi-domes built in courses radiating from a centre in the back (Hamilton 1959, figs. 49a and b). At Mafjar the stonecutters displayed their expertise in a rather eccentric manner: from the apex of the semi-dome a chain of cut stone was suspended, ending in a sort of tear-like pendant (fig. 12c). All the pieces of this feature (including the interlocked links of the chain), were carved from a single piece of limestone (Hamilton 1959, p. 91).

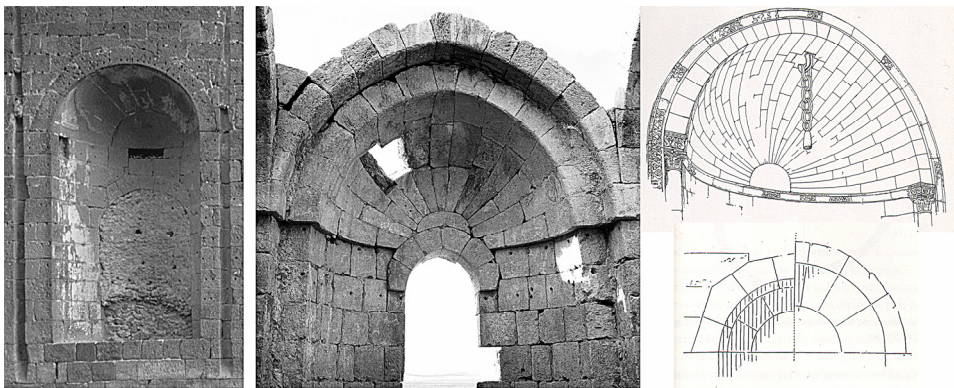


Figure 12. Semidomes with radial joints. A: Shahba, Roman baths; b: Hammam as Sarraj; c: Khirbat al-Mafjar; d: Jerash & Musmiye (Choisy 1883).

At the unfinished palace of Mshatta, the exedrae of the triconchos throne hall were certainly intended to be covered by brick semidomes, not being so clear how was planned the roofing of the remaining central space, being possible or a pyramidal roof or a timber dome.

Timber domes

In these cases we are again clearly dealing with elements with a strong Byzantine influence in terms of technique and shape: the double wooden ‘Dome of the Rock’ (*Qubbat Al-Sakhra*) is set on a high drum, pierced with windows by means of transverse wooden wall-plates. This setting on top of a

pierced drum explains by itself the choice for such a light structure, as no other one could have been built on top of it (**figs.13a&b**). The antecedents are traced in the St. Simeon Stylites church (dated in the 6thC.AD), that according to Krenker, was designed to have a wooden dome, arranged to be set on a masonry drum by the very same method employed at the Dome of the Rock (Abh. Der Preussischen Akademie der Wissenschaften, 1938, phil.-hist. Klasse, No.4, pp.15-20, quoted in Creswell 1989). A similar solution is the adopted at the nearby and smaller Dome of the Chain (*Qubbat As-Silsiyya*) also at the Haram as-Sharif of Jerusalem (**fig.13a**, foreground). On the contrary, nothing is left of another famous wooden dome from the Damascus Mosque: the Dome of the Eagle, or *Qubbat an-Nisr* (according to Creswell, its correct original name would have been the “Dome of the Gable”, (1989, p. 52)). It is supposed that it would have rested on great cross beams.



Figure 13. Wooden Domes. Jerusalem. a: Dome of the Rock & Dome of the chain; b: Dome of the Rock, section (model from the David’s Citadel Museum).

CONCLUSIONS

The process of merging western and eastern architectural models, building techniques and materials, carried out during the Umayyad period allowed the creation of a new expression of architectural and urban tradition required by the new power, that was to liberate Islamic material culture from antiquity. This process provided a new formal and technical catalogue for a new emerging culture and guaranteed the survival of “antique” cultural practices and elements, from both eastern and western traditions that otherwise would have been lost. This balance between continuity and change can be recognised particularly in the case of the city and the “urban culture” that was preserved thanks to the transformation process operated on it, that far from neglecting the “classical city” meant its preservation and revival.

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