Anastylosis of Apsidal Roof Engineering for Ecclesiae of Hawrān during Late Antiquity: Case of Julianos Church in Umm el-Jimal, Jordan

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Research Article

Keywords: Late Antiquity, buttressing apse, composite structure, relieving diaphragm, antiseismic configuration, Hawrān

Posted Date: March 30th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1452501/v1

Abstract

Umm el-Jimal, located in Hawrān of Late Antiquity, is well-known for the use of volcanic-based building materials; mainly basalt stone and scoria. Structural attributes of these two materials are important for examining potential roofing system(s) that could have been used for the semi-circular apse of Julianos Church in Umm el-Jimal. Since the roof is demolished nowadays, the study examines two interpretive theories presented in literature: ‘vault roof’ as put forward by Professor Howard Butler in 1913 and ‘corbelled flat roof’ as suggested by Corbett and Reynolds in 1957. A third theory is also introduced in this study, based on available archaeological remains, relevant cases, and religious and scientific premises. It advocates a ‘composite system’ of corbelled relieving diaphragms and non-load-bearing vaulted structure to generate a box-like buttressing apse. The composite system can operate interactively to resist static loads and dynamic seismic forces. Builders of Hawrān should have introduced novel engineering of their ecclesiastical architecture that differs from its ‘classical’ counterpart. Contemporary conservators can respectively consider these theories in their attempts to salvage the alarmingly vanishing *ecclesiae* of Hawrān.

Roofing System(S) For The Sacred Apses In Umm El-jimal In Late Antiquity: Debating The Construction Engineering

Ancient architecture form and the design conceptions on which it is based inevitably have structural resonance at their heart. Contemporary studies are constantly returning to earlier buildings to explore their distinctive building techniques and structural principles. Ecclesiastical buildings are no exception, especially those located within the Mediterranean and Syrian region as they witnessed the birth of early church architecture. Of particular interest is Syria. It provides researchers with examples to look at the first models of church architecture and explain their structural engineering. In particular, Hawrān region, historically recognized as the area that includes parts of South Syria and North Jordan, contains hundreds of churches from the fourth, fifth, and sixth centuries; some of which in complete ruins and others partly destroyed. For example, churches in Umm el-Jimal are in so bad a state of preservation that anastyloses is necessary for a reconstruction of them to as much as their original architectural and structural estate.

Conception of church architecture in Hawrān is challenged by tendencies of former scholars to portray this type of architecture with its classical equivalents; relaxing by that localized perspectives that could address factors influencing the produced architectural and engineering norms. Professor Howard Crosby Butler, a renowned American architect, visited the region in October 1899 for eight months, and revisited it through the Princeton University Expeditions between 1904 and 1905. He, along with other former scholars, such as Melchior de Vogüé and Gottlieb *Schumacher, p*rovided a rich description of almost all the Syrian churches during Late Antiquity and published their works in several volumes (see for example [1, 2, 3, 4]. Their publications became the main source of information about ancient Syria and its church architecture. Among the varied architectural evidences that reflected the different aspects of life in Hawrān church architecture stood out as the most affluent in design and structure. Current study relies on these publications because they have posed questions and gave evidences of conflicts whether the roofing systems of ecclesiastical architecture should be configured with the vaulted ‘classical prototypes’ or as a real manifestation of engineering invention of local builders during Late Antiquity.

The intent in this study is to transform our understanding of a historic building from one which is focused solely on formal, stylistic, or contextual issues to one in which the real structural problems and building techniques addressed by the builders of the time are given their proper credence [5]. There barely exists any study that tackles the development of structural engineering and systems that accompanied church architecture during Late Antiquity. To our knowledge, none of these systems has been tested rigorously, except for the famous churches of Constantinople St. Eirene and Hagia Sophia (see for example [6, 7, 8]). Further research is required on the construction methods that marked the emergence of church engineering in other regions [9]. The present work seeks to contribute to filling this gap in order to discover the main critical issues and to highlight the major development in construction technology that marked ecclesiastical architecture during Late Antiquity. More importantly, it should provide a foundation for the theory of conservation by relating architecture to structural concepts, in turn, to ascertain appropriate reconstruction procedures for the remaining ecclesiastical structures distributed within the cities, towns and villages of Hawrān. For example, Umm el-Jimal, an old town in Hawrān (Figure 1), barely witnessed rigorous conservation or restoration works for the roofs of its buildings. Part of this could be related to the fact that experts conducting conservation works are not familiar with possible construction roofing systems that could have been adopted by builders of Umm el-Jimal in Late Antiquity. The findings of the study should assist both conservators and archaeologists in their attempt to understand the engineering history of these structures in Umm el-Jimal and elsewhere in Hawrān. It should provide guiding principles for understanding the scope of roofing systems for ecclesiastical architecture that utilized basalt stone as its main building material since the early fourth century.

Anastylosis is justified for churches in Hawrān because this region witnessed the introduction of what Michael White termed as the *aula ecclesiae* (ecclesiastical hall) [10] as well as *basilica ecclesiae* that dominated church architecture in this region from the fourth to the sixth centuries CE. The styles were developed in Hawrān by the Arabs who lived on the fringes between the Roman and Persian empires. Ifran Shahȋd’s landmark study on “Byzantium and the Arabs in the Fifth Century” investigates the establishment of the ‘Arab Church” when the Arabs were under the authority of the Western Church from Constantinople [11]. Arab Christian tribes established centers within the province of Arabia. The period during the third to the sixth century involved several tribes who converted to Christianity and served as allies to the Byzantines, including the Tanukhids, the Salihids, the Lakhmids, Kinda, and the Ghassanids [12]. The fourth century saw the rise of the Tanukhids who revolted against Rome. It was also the century that witnessed the early Christological controversies through which the provinces and their bishops were directly involved (specifically Bishop Beryllus of Bosrā).

Amongst these circumstances, it could not be suggested that the Tanukhids adopted massive church building projects. Nonetheless, they had an important role in establishing the early models of church architecture in Hawrān. Butler provided a classification of early churches of Hawrān (as well as the

Northern Syria and Central Near Eastern Syria) and categorized the churches as classes and types; based on their architectural configuration and plan formulation. He provides a descriptive analysis of these churches, especially *aula ecclesiae* and *basilica ecclesiae* that permeated the Hawrān region starting from the fourth century. Essentially, *ecclesiae* in Hawrān were not subject to standardized styles. Alterations in their architectural style are mainly marked in the sanctuary zone; its spatial configuration and its architectural form. It is believed that while the rectangular apartment apse was the norm in early Christianity worship places, the semi-circular apse became acceptable in the local architecture in Hawrān after the official introduction to Christianity during the Byzantine era [13]. The height of the apse is one storey high in most of Hawrān churches with few exceptions where it goes up to the full height of the church such as the Chapel of the Barracks in Umm el-Jimal [4, 14].

Another noticeable change is the employment of diverse roofing systems in the apsidal zone. Some cases are attested with atypical flat corbelled roofs constructed with basalt slabs. One prominent example is the rectangular sanctuary at the east end of the Chapel of the Barracks in Umm el-Jimal. The Chapel is dated in the year 345 CE [14]. The roofs of the sanctuary, along with the side spaces, the middle and side aisles, were all covered by a flat slab roof at one level [14]. Similarly, Lubbēn churches (the Large Church and the Chapel) in el-Ledjā region in Hawrān exhibits atypical flat roofs in their sanctuaries [15]. Founded in the fifth century (probably 417 [15, 4], its architecture is considered the only surviving examples with flat roof covering a semicircular apse in Hawrān and elsewhere within the Christian world [15, 4]. Incorporation of this atypical flat roof is advanced with the fact that builders of Hawrān barely built with domes of cut stone, as the architects of Northern Syria did. Even when they used half-domes for sheltering the apses, the domes were built of small-sized lightweight scoriae that were set in mortar. Examples are found in el-Ledjā in the Chapel of square plan in Der idj-Djuwani chapel and Wakm Chapel that exhibited a large projecting apse with a fallen half dome [15]. In Umm el-Jimal, Butler recorded two fallen domes in the North Church and the Northeast Church [14]. The only church that still exhibits parts of a fallen half-dome is the West Church.

One of the distinguished *ecclesiae* in Hawrān is Julianos Church in Umm el-Jimal (Figure 3) [2]. It is composed of two main spaces: the open hall, including set of transverse arches, and the sanctuary in the form of semi-circular apse that stretches along the width of the nave (Figure 2). It is a useful case for tracing church engineering in Hawrān, especially the roofing system for its apsidal compartments. Although the apse is currently in a bad state of preservation (Figure 2), it has been repeatedly discussed in literature. Scholars provided two diverging roofing theories for its apsidal area: a typical vaulted half-dome (as suggested by [14]) and an atypical corbelled flat slab (as suggested by [17]) (Figure 2A, B). Current study discusses the two theories with reference to illustrations and drawings provided by their scholars. However, our fieldwork observations in the archaeological site of Umm el-Jimal along with existing reports and comparative studies with other cases in Hawrān region, invites us to introduce a third approach for theorizing apse roofing system in Julianos Church. We refer to both scientific and religious factors for explaining the rationale for this theory. Henceforth, the study tackles three main hypotheses for roofing construction of the semicircular apse in Julianos Church:

- Theory one: a '*half-dome vaulted roof'.* It is based on the documentary and reconstruction drawings provided by Professor Howard Butler and the Princeton University Archaeological Expedition to Syria in the years 1904-1905 (Figure 2A).
- Theory two: a '*corbelled flat roof'.* It is based on the reconstruction drawings provided by Corbett & Reynolds in 1957 in their study entitled as "Investigations at Julianos' Church at Umm-el-Jemal" (Figure 2B).
- Theory three: a '*composite system of roofing'*. It is suggested by this study based on archaeological remains, comparative analysis with relevant examples, and contextual reading of ecclesiastical architecture in Hawrān region.

The study starts by introducing the main building materials experienced in Umm el-Jimal in particular and Hawrān region in general. It then examines the variability of roofing construction of the apsidal area of Julianos Church in Umm el-Jimal in relevance to published studies, excavation reports, and field observations. It concludes by advancing a holistic perspective for comprehending ancient building techniques for church architecture in Hawrān during Late Antiquity.

[2] Due to lack of a concrete archaeological evidence for dating Julianos Church in Umm el-Jimal, scholars suggest different time refernce for Julianos church: the 4th centudy (according to [4, 14, 16]); the 5th century (according to [17], and the 6th century (according to [18]).

Umm El-jimal: City Of Volcanic Building Materials

Umm el-Jimal witnessed the advent of several civilizations and settlers including the Nabataean (50-106 CE), Roman (106 – 300 CE), Byzantine (5th – early 7th century CE), Islamic era (661 – 900 CE), Druze who migrated southward from Syria (1905 – 1935 CE) and Mas'eid Tribe (1935 – 1950 CE). Local Nabataean nomads settled at Umm el-Jimal because it was under the influence of the nearby Bosrā- the city located to the north of Umm el-Jimal which became the late Nabataean capital and later the capital of the Roman province of Arabia, Provincia Arabia (Figure 1). The Romans constructed the town as a military station and constructed a fort (castellum) [16]. During Late Antiquity the town took the form of a rural farming and trading town of about 6,000 - 8,000 people; most of which converted to Christianity. Accordingly, the town witnessed the spurt of church construction (about 15 churches) and over 150 domestic houses (Figure 3) [19]. Construction of buildings was enabled because of the availability of two sole volcanic materials: basalt stone and lightweight scoria.

Basalt

Basalt stone is considered the main building material of construction and engineering in this region. Before 15 million – 65,000 years ago, volcanic emits in the Jebel Druze erupt over the Hawrān Plain of

Northern Jordan and Southern Syria, covering it with about 300 meters thick deposits of basalt. Basalt stone was heavily used not only because of its availability but also because of its physical properties [20]. It is a hard, dense steel blue volcanic rock that is primarily composed of iron and magnesium along with other fine-grained mineral structures such as olivine, hornblende and augite [20]. It might be fine grained due to rapid cooling of lava on the earth's surface or porphyritic containing larger crystals in a fine matrix or vesicular or frothy scoria [21]. Of course, the physical and mechanical properties of basaltic rocks used as main building material in historical buildings in the Hawrān region (including Umm el-Jimal) show great diversity depending on the place of origin[3].

Strength of basalt stone in tension and compression encouraged its use as a load bearing structure [21]. Its compressive strength allowed the builders to build tall walls and raise their buildings to two or three stories[4]. Its tension strength was also structurally used to introduce cantilevering techniques by projecting corbels for roofing from the walls [20]. Thin basalt slabs were laid upon the corbels and stretched to cover roofs in single or multi-storey buildings [20] and for rectangular and semicircular compartments (Figure 4A, B). It is also utilized to build framed structures (lintels, beams, etc.) or transverse arches to support the roof because of its ability to resist potential deformation and the thrust that causes horizontal pressure and lateral displacement. More importantly, it was used as cantilevers for constructing flying staircases and over-hanged balconies (Figure 4C).

Scoria

It is expected that construction of vaulted roofs in apses was enabled due to the availability of local light materials such as the volcanic scoria. Dodge should have supported this theory because he declares that architecture of the Roman East interpreted that of Rome’s with employing local materials and techniques [23]. He suggests that whilst the areas of Hawrān (and Cilicia in Southern Turkey) do not have Roman concrete as the type used for vaulting techniques in Rome and Italy, builders in this region employed alternative material of light volcanic scoria [23]. They used it for building vaults during the Roman period, i.e., when Hawrān came under strong Roman influence in the early second century CE and Bosrā was established as the capital of the new Province of Arabia [23]. Examples are found in the Roman baths in Bosrā that were presumably built in the third century and also some churches such as Bosrā Basilica and Bosrā Cathedral- as will be discussed later in this study.

Fortunately, we were able to trace some fallen remains of the scoria-based lightweight mortar that was used for building the dome in the West Church in Umm el-Jimal. Khaled Al-Bashaire archaeometrically examined the mortar, and tried to determine the source of the scoria. He found that the mortar is lime-based and hydraulic and its petrographic analysis showed the presence of basalt, grog, mortar remnants, and charcoals added to the lime binder [24]. It is different from the mortar and cementing techniques used during the Roman period at the city of Gerasa (Jerash), which was calcic lime, slaked with minimum amount of water, and contains natural aggregate sources including calcite, gypsum, and quartz; or calcium, gypsum and crushed pozzolana [25].

Although these studies remain crucial for determining the age of the buildings, it, nonetheless, does not clarify the structural performance of the lightweight scoria and hence its engineering decisions. It is suggested that the lightweight volcanic rocks such as scoriae were used during the Roman period to reduce the weight of the vaults and consequently reduce the lateral forces on the buttressing walls and control the forces generated by the structures themselves [26]. In such means, factors such as the availability of certain building material, their structural behavior and their properties should determine the norms of structural treatments, building techniques, and, by essence, its architectural geometry. Next section refers to the unique volcanic materials in Umm el-Jimal (basalt and scoria) to shed light on three theories that explain the roofing engineering for the sacred apse in Julianos Church –the oldest dated church in Hawrān during the fourth century.

[3] Geologists conducted experiments for investigating the geochemical, mineralogical, and magnetic characteristics of the basalt stone in the Tertiary–Quaternary field of Harra El-Jabban, specifically from (Umm Al-Qutein) area. It was found that the mineralogy of basalt is characterized by a presence of calcic plagioclase feldspar, pyroxene, olivine, iron oxides such as magnetite, ilmenite and iron-titanium oxides (Titanium-augite, sphene) and spinel [22, 21].

[4] Some buildings were raised to six stories such as the Barracks' largest tower [20].

The Circular Apse Of Julianos Church: Discourses Of Engineering Systems

Despite the existence of fifteen churches in Umm el-Jimal, there exists no single example that signifies for certain what roofing materials or construction techniques were used, especially for the apse zones. Apart from signs of buttressing and the thickness of the walls that might poorly point to the use of certain roofing system, the materials used for the apses in Umm el-Jimal have left some traces that might be used to suggest potential building materials or techniques that were utilized in the apse. Three theories could be addressed to explain the relationship between design decisions, building materials, and structural systems (Figure 5).

Theory One: Apse with a half-dome vaulted roof

Stone builders in Umm el-Jimal never experienced the round plan. Their planning remained mostly rectilinear. A conception for using the semicircular apse as an architectural feature in church architecture evolved during Late Antiquity. Butler recorded apses of churches and chapels in Umm el-Jimal; all configured with half-dome including Julianos Church. Reconstruction drawings of Julianos church are illustrated in Figure (6). They are based on the section and plan provided by Butler in *ill.* 147 and *ill.* 148 [14].

The drawing shows a semicircular apse with a radius of 3.80 meters and a height of 8.48 meters from the ground. The thickness of the semicircular wall is 73 centimeters. It exhibits a window at a height of 3.9 meters; above which the half-dome is directly placed. Thickness of the arch of the half-dome is about 50 centimeters. Butler's original drawings do not identify the materials that were used for constructing the half-dome. Besides, it is not clear how the half-dome is attached to the apse bearing wall (abutment). The bottom of the half dome is slightly projecting off the wall from within. Hence, the drawing stands short for demonstrating the structural behavior of this half-dome. If we accept the fact that the builders used scoria bonded with mortar for constructing monolithic lightweight vaults, an argument could be placed for discussing Butler's half-dome theory.

Butler described the status of Julianos church when he visited Umm el-Jimal in 1904-5 by stating: "The building [i.e., Julianos Church] is unfortunately in a sad state of dilapidation. So great is the mass of debris within it that it is not easy to trace its outlines without time and care; but when these are applied, a complete plan of the church itself can be made out owing to the very simplicity of the design. *The apse is preserved to the springing of its half dome*" [14] (emphasis is added). His description does not necessarily correspond with the image that he captured on the photograph he took during his visit (Figure 7). The photograph, showing a view from the southeast for the apse of Julianos Church, portrays the wall being partially demolished and extending to its full height and width at the northern section. The wall is composed of two stone skins with bonding mortar.

Lynne Lancaster discusses the structural behavior of a vault system, including the domes and half-dome [27]. A dome normally involves forces that are occurring in both directions of curvature: meridional forces and circumferential hoop forces. Circumferential hoop forces are challenging in structural stability of the dome because they are transformed into hoop forces that can change from compression to tension in the haunches. Theoretically, stability of the structure depends on the abutment: its width and height [27]. Reducing the impact of the hoop tension at the haunches is achieved through controlling the weight of the materials. The lighter the materials at the crown and the heavier they are at the haunches, the more likely that the dome would be able to counter the lateral thrusts by reorienting them downward onto the abutment [27]. In other words, it reduces the effect of the gravity. Equally important is the ability of the abutments to resist the lateral thrust imposed by the half-dome. In fact, and according to Butler's theory of the half dome, such sequence in the structural behavior could not be essentially traced in the apse of Julianos Church. In reality, the apse wall maintained its full height; leaving no indication for previous utilization of the wall as a supporter of a half-dome. Besides, the wall maintained its full thickness. It does not exhibit a recess that indicates a bedding ledge for the half-dome- as noticed in Figure (7).

Butler's photograph does not verify that the half-dome was placed on wall abutment that secures its structural stability. There can be little doubt as to the accuracy of Butler's description and the restored drawings which shows the apse side of Julianos church and a cut through it. In fact, John Wilkinson warns us to be cautious with Butlers' documentary work in Syria especially that. He tended in his study "What Butler Saw" to question the reliability of the observations and measurement made by Butler during his expeditions to Syria [28]. He claims that Butler's work contained 'imperfections' because of errors in measurements (in comparison with contemporary surveys) and simplified methods of measurements that excluded triangulation and diagonal measurements. Indeed, the imperfections lie not only in measurements and numbers but might appear in the structural interpretations of the architecture he saw. Such 'imperfections' might conceal local creativity in the architecture he documented. Besides, theory of vault roofs might challenge the value of stone engineering that distinguishes Umm el-Jimal and its neighboring cities in Hawrān- the corbelled flat roofs. This invites us to discuss a second apsidal roofing theory introduced by Corbett & Reynolds in 1957- a flat basalt roof.

Theory Two: Apse with a corbelled flat roof

It is assumed that builders of church architecture in Umm el-Jimal developed new skills of structural engineering and building techniques because they knew the properties of the sole type of stone; the basalt stone. Building techniques relied mainly on corbelling systems.

Corbelling acts based on the cantileverprinciple [29]. It isa complete structural system in which "cantilevering long, finger-like stones in a wall as ledges on which stone beams are then placed in order to create a ceiling or roof". Horsfield also defines the corbelling as a building technique "in which two or three rows of corbels project from the walls with long slabs resting on the tips of the upper row to form floors and roofs" [16]. In this case, long slabs of basalt were resting on corbelled courses. Larger spaces were solved through incorporating transverse (or girder) arches [19]. It is called 'arches supporting stone slab system' in which plans are roofed with long, thin stone slabs supported on a series of transverse arches composed of small blocks that are laid dry [23]. This means that building stability and sustainability is dependent on the actual mechanisms of the techniques involved in building these structures. Several church halls exhibit monumental transverse arches that were attached to internal buttresses to take the thrust of the arches and transform it into the ground [16].

Realizing the capabilities of basalt stone in constructing flat roofs along with the existing remains of transverse arches, Corbett and Reynolds provided reconstruction drawing depicting the roofing system for the apse in Julianos Church with flat double-corbelled roof resting on the transverse arches and covering the entire apse at two different levels (Figure 8) [17]. Basalt is used in building the roof as dry construction technique (stones with no mortar joints). It differs from the wall construction techniques; most in which basalt masonry walls were filled with rubble and lime mortar[5].

Fortunately, there exists a marked local example in Umm el-Jimal, the Barracks Chapel. It is located in the southern part of Umm el-Jimal and was built one year after Julianos Church (in 345 CE). According to Butler, the church exhibits a flat apsidal roof, built with corbelled flat slab structure (*ill*. 144 in [14]. Another regional example for the employment of flat structural technique appears in Lubbēn- an ancient village in el-Ledjā, Hawrān. When Butler visited Lubbēn he observed the well-preserved architecture of its two *aula ecclesiae*; the Large Church and the Small Church (the Chapel) and seemed surprised by the absence of the half-dome roof. He reports the covering of the apse in the Large Church as "not a half dome…[but] corbels [that] set on either side and connected by a heavy stone beam" [15]. Similarly, the apse in the

Chapel is “roofed by means of a corbel course set upon an in-curving wall and carrying slab” [15]. Butler’s documentation of the Large Church shows the flat-roofed apse that resulted from using the corbel system supported by transverse arches (Figure 9).

Although there exist real examples that support the ‘flat roofing’ theory for sheltering the apse in Julianos Church, it is still uncertain if we could generalize this structural theory to all churches in Umm el-Jimal or other areas within Hawrān region. It is worthwhile noticing that using a flat slab at the apse zone suggests a continuous flat slab to cover the entire church (nave and apse) - as seen in Lubbēn Large Church (Figure 9)[6]. Similar treatment is not noticed in case of Julianos Church where Corbett and Reynolds depicted the roof of the nave with pitched wood structure as seen in Figure (2B)[7]. Besides, it should be sensible to approach Julianos Church through the real environmental factors that accompanied the early settlements of Christian people in volcanic Hawrān region- the region most vulnerable to natural hazards of earthquakes and landslides.

Theory Three: Apse with a composite system of roofing (corbelled roof and lightweight arcuated semidome)

A central case to consider when tackling monumental structures in Hawrān region is the South Bath of Bosrā, built between the second and third century [31]. According to its current status, the roofing system in this building is depicted with two layers: a non-load bearing lightweight arcuated shell and a flat corbelled basalt slab (Figure 10). It is a unique style of roofing that invites us to advance a third theory for examining the roofing of church structures in Umm el-Jimal: a ‘*composite system of roofing’*. When adopted in church architecture, this theory should be examined based on two premises; one is religiously symbolic and the other is scientifically structural.

Premise one: Church architecture in Byzantine period is subject to theological and liturgical standards- a factor that affected the spatial and internal morphology of the church and its symbolic resonance.

Churches of the Byzantine period are very limited in their architectural morphology [33]. One important component in its geometrical configuration is the dome. Culture of ‘domed churches’ is informed by the earlier classical Roman basilicas such as the *Basilica of Maxentius* [34]. It has been claimed that Constantine promoted these forms of church architecture which eventually influenced the western half of the Roman Empire and later the eastern Provinces [35]. The plethora of Early Byzantine domed churches in Asia Minor, Constantinople, and in Syria indicates that architecture in this region was strongly influenced by the perception of the domical shapes and its influence on the city image [9]. Similar emphasis on the domical representation is also noticed in the interior design of early church architecture, especially at the apse zone. Generally speaking, there is a tight connection between the interior of church architecture and the liturgy of ritual; especially through its arts and embellishments. Church interior is considered part of the system of symbols in which its design, treatments, details and arts bear theological meanings and liturgical uses [36]. Through its symbolism, churches are transformed into more than a place of worship; it is a statement that reflects the fundamental beliefs of its people [37].

Within this context, the apse is designed to provide smooth surfaces suitable for the presentation of certain symbolic images because the apse is seen as an image of the cosmos symbolizing heaven and the earthly world [37]. Hence, the apse displayed only the most sacred persons (Christ, the Virgin, Angles) or scenes imagined as taking place in heaven. Displaying this image determined the form of surface; usually domical [37]. The images should be represented in frontal attitude in order to face the beholders and meanwhile allow the depiction of actions, especially in a scenic image.

Symbolism in church architecture means that there exists a strong correlation between the geometric theory and the religious symbolism, i.e., the arcuated geometry of the apse roof and the displayed image. Certainly, the images would have been less effective within the total composition of the church interior had the architectural surface of the apse been flat. It is difficult to believe that this symbolic meaning would have been intuitively clear to clergy and laity alike in the absence of the traditional domical shape. Accordingly, this symbolic need suggests an arcuated geometry inside the apsidal zone of the church. This should give an acceptable justification for the use of the nonstructural semidomical shape at the apse in Julianos Church in Umm el-Jimal; as previously discussed in Butler's theory. Apparently, Butler related the plan of Church of Julianos to that of the *'Kaisarîyeh' at Shakkā with the apse being evidently copied from that of the Basilica of Bosrā (also known as* Dȇr Bohȇrā)[8] (Figure11*) [4].*

Whilst acknowledging the religious imperatives of church architecture, a simple arcuated semi dome proposal might challenge the hazardous conditions that could have accompanied the construction projects in Umm el-Jimal. According to the single 'arcuated' theory, the old masonry buildings did not necessarily follow anti-seismic criteria. This leaves the monolithic lightweight non-bearing load semidome of the apse highly vulnerable because of the complete absence of effective connections with the basaltic wall (see Figure 11B). The solution is hypothetically friction-based; providing poor or absent integration between the structural elements and causing weak load transmission. In this condition, the arch face tends to overturn when the equilibrium in the nave wall is disturbed during an earthquake or a roof collapse.

It is well known that Umm el-Jimal witnessed occasional earthquake jolts and a severe earthquake in 747 CE that led to a comprehensive demolition of the entire town. It could be hardly presumed that the builders carried the heavy masonry basalt stone for constructing the roofs of their buildings without giving due consideration to antiseismic engineering in the volcanic Hawrān region. Certain earthquake prevention techniques should have been considered in building engineering in Umm el-Jimal. After all, the region of the Middle East, including Syria and Jordan, has a long and constant history of earthquake activity [38]. Historical references record about 300 earthquakes that have taken place in the Dead Sea basin since 2510 B.C.E.; ten of which were drastic and caused severe damages [39]. Earthquakes remained the main cause of disasters in the East Mediterranean Region and its impact is expected to continue in the future as it is associated with the northward movement of the Arabian plate [39]. In light of these circumstances, it should be sensible to consider that builders of Umm el-Jimal have sought to construct feasible, functional, but, more importantly, sustainable constructions that would last long and survive earthquakes.

Premise two: Umm el-Jimal is located in a seismic region that demanded antiseismic treatments through structural reinforcement

To prove resistance of buildings against earthquakes, some strong evidence should be observed through the lens of *seismicarchaeology* that focuses on human construction and his effort to resist earthquakes or otherwise reduce their effects [40]. This evidence could be borrowed from ancient cases. In their landmark book on 'Building Configuration and Seismic Design: The Architecture of Earthquake Resistance', Christopher Arnold and Robert Reitherman discussed the seismic design process and its ability to generate architectural configurations, engineering treatments and material employment that resist seismic hazards [41]. It is corroborated that builders of historic architecture did not obtain an analytical approach to seismic design. They, nevertheless, responded to the nature of lateral forces of wind and buckling and created an analogy for seismic design (Arnold and Reitherman 1981: 201). Essentially, resistance to earthquakes has formed indispensable part of architectural innovation in most civilizations; enabling many vulnerable monuments to survive for several centuries despite lacking reinforcements and tensile materials that would strengthen the building against the dynamic motion caused by earthquakes.

In light of the profusion of compressive materials and dearth of other tensile materials in historic structures, 'configuration' remains the only available tool of seismic design [41]. Ancient approaches for configuration-based remedies against earthquake damage could be governed under two main categories: *prevention-based* configurations and *protection-based* configurations. *Prevention* is achieved through 'seismic isolation' that avoids earthquake forces from entering to the structure [42, 43]. It acts based on energy passing-through system[9]. Good examples of this mechanism are traced in ancient columnar buildings that are constructed on orthostat stone layers (usually three layers) such as the Parthenon, King Cyrus Tomb in Pasargadae built in 550 B.C.E, the Ormetash Obelisk built in the 4th century C.E, and many others.

Protection configurations are used to strengthen the building against dynamic forces and its collapsing effect. It acts based on energy absorbing mechanisms [42]. It involves several mechanisms, including:1) the utilization of ductile construction materials (such as timber) that withstand the demands imposed due to large deformations of the structural elements; 2) the employment of robust architectural forms (such as buildings of symmetric plan and form) through which the earthquake-resistant features are equally distributed in the building, and hence have the ability to equally resist earthquakes from any direction; 3) the insertion of light-weight nonstructural members to act as bands that tie the walls together and enable the dissipation of inertia forces to all walls, and hence reduce the effect of seismic forces on the building; and 4) the application of resilient structural configuration (such as walls or frame-based systems) [44].

Perfect protection configuration appears in many historic buildings. For example, Roman architecture, and in light of the deficiencies in the material properties, developed internally generated lateral forces relying on the shear mass of the building. Extremely thick masonry walls provide a vertical gravity force that stabilizes the building against any lateral forces. Friction between massive overlayed masonry surfaces is an added value for fastening and strengthening the building against lateral movements. Byzantine architecture developed new configurational measures for lateral resistance that rely on 'structural equilibrium' configuration. It is a system that utilized pendentives to convert the uniform outward thrust of the large span shallow dome (arching thrusts) into forces at the pendentive corners supported by huge buttresses [41]. The volume and mass of the buildings spread out toward the base to achieve equilibrium distribution of lateral and vertical resistance. Similarly, Gothic architecture, seeking lighter masses of architecture, relied on strategies of point-for-point buttressing of lateral thrusts and more efficiently shaped arches [41]. The system of flying buttresses increased the effective width of the structure against lateral arching thrusts and overturning.

There exists no historical evidence of antiseismic techniques that could have been employed by builders of Hawrān region. Apart from the tie courses that were installed in wall construction and interlocking stones [30], there exist no solid indications of a deliberate antiseismic construction (such as foundation isolation, metal reinforcement of stonework (such as clamps, dowels, anchor bars), wooden frames, etc.). Nevertheless, since antiquities, builders of Hawrān region invested in the sole building material of basalt stone to develop a corbelled system technique; the basaltic corbeled bearing system. They used it for constructing roofs and ceilings- the parts most vulnerable to the seismic actions of an earthquake. In due respect, the corbelled system could have been accustomed as an antiseismic technique that simultaneously resists static and dynamic loads in the higher parts and corners of the buildings.

Structures in Hawrān are based on a corbelled buttressing system; buildings are constructed with nonreinforced load-bearing masonry walls and transverse arches (girders) that support flat corbelled *roofing slabs.* The 'buttressing; ideology is also used to strengthen structures incorporating arcuated compartments that are prone to damages caused by static and/or dynamic forces. This is noticed in the cases of Bosrā Cathedral, built in 512-3 in Bosrā and St. George Basilica, Zor'ah, built in 515 CE [31, 1] (Figure 12). Reconstruction drawings and photos provided by earlier scholars (Butler and de Vogüé) represent the church building with what Butler termed as '*buttressing apses'* (Figure 12)[10] [4, 2]. *The Buttressing Apse is suggested as a 'strengthening' and 'stabilizing' element for church architecture constructed in the Hawrān region. Since the central dome is constructed as a non-load bearing unreinforced lightweight structure, it is suggested that the semidomical apse is able to perform a buttressing role. Nevertheless, buttressing performance requires* adding surcharge above the haunches and constructing an abutment that is capable of resisting lateral thrusts [27]. According to Lancaster, ability of the abutments (in our case the apsidal bearing wall) to resist lateral thrusts depends on (1) abutment thickness and (2) abutment height [27]. Stability of the entire system is affected in case there is change in the measurements of the abutment or if the supplementary weight that forms the surcharge above the vault (such as mortared rubble fill) is reduced. A surrogate reinforcing system is certainly needed.

Buttressing Apse could be approached in this study as a composite configuration of flat load-bearing corbelled beams and an arcuated non-load bearing lightweight semidome. The composite system configures a box-like construction that should have sustained compressive gravity-load stresses but, more importantly, served as an antiseismic mechanism. There should be no doubt that this antiseismic construction technique could have been considered by builders of Umm el-Jimal when they established Julianos Church. The remining apsidal wall that appears in the photo that was captured by Butler during his visit to the region should help us better examine the composite theory and demonstrate its mechanism (see Figure 7). According to the photo, the remaining apsidal wall is at its full height; interrupted by two layers of projecting corbel courses. Based on these structural features, a three-dimensional reconstruction drawing that depicts the buttressing apse as a '*composite system of roofing'* in Julianos Church is illustrated in Figure (13).

According to this composite theory, a *lightweight half dome, built of volcanic scoria and cement,* rests on a row of cantilevering stones in the apsidal wall (ledges) (the lower corbel in Figures 7 and 13). Another layer of loadbearing structure should have been added to take off the forces and protect the lower half dome. In such means, the corbelled structural layer could be described as a *Relieving Diaphragm*. Diaphragms have two roles [45]; the first is to transmit static and dynamic forces horizontally and provide continuous load path for the static and seismic forces. The second is to tie the vertical elements together so that these elements could comprehensively resist the seismic forces, i.e., it secures the box-like effect of the structure during an earthquake.

- Structural buttressing of the Relieving Diaphragm through securing load path continuity:

The compound building of the church (composed of the two compartments of the nave and the apse) should comprehensively act as a load bearing structure where the load is transferred from the roof and moves vertically downwards through the walls toward the foundation. The lightweight monolithic half dome is acting as a non-load bearing shell that does not bear any additional weight of the church's structure other than its own. Relieving diaphragm carries the in-plane shear away from the half dome. The relieving diaphragm thus minimizes the maximum tensile stress that could affect the unreinforced portions of the system and provides a 'safe' thrust domain for the non-bearing load half dome, especially during earthquakes.

- Seismic buttressing of Relieving Diaphragm through 'tying and anchoring': Collapse of roof structures covering ancient churches often takes place during earthquakes. Mostly, the roof is engaged in the collapse along with the underlying masonry structure, producing complete damage. Damage mechanisms are of two types [46]. The first occurs in the transversal direction in the nave section where collapse of the roof is usually followed by a collapse of the nave wall (or the clerestory). The second occurs in the longitudinal direction along the nave (also known as transversal motion). Unreinforced roofs, usually exhibit lower stiffness in this direction, pushes the top of the nave wall with horizontal inertia force, causing out-of-plane bending. The nave wall undergoes large displacement under the earthquake motion; resulting in roof collapse but also in forming excessive deformability that affect the apse wall. Out-of-plane collapse of the apse façade thus follows. In both cases, failure of the church structure to resist earthquake motion is implicitly related to two factors [46]. The first is the roof behavior; its construction technique has a critical role in triggering (or limiting) the development of a damage mechanism. The second is the insufficient connections between the vertical planes and between the roof surface of the apse and the walls, which is the case in most ancient structures, where the walls of each segment of the church have been built separately [46]. Better connection between the diverse planes of the structure (horizontal and vertical; walls, floors and ceilings) is addressed in contemporary literature as one of the most important factors for improving the seismic safety of the nonstructural masonry structure (see for example [47, 48, 45].

Employment of a load-bearing diaphragm transforms the apse into a buttressing structure that strengthens the seismic response of the building. According to Sathiparan [49], diaphragm construction should consider two conditions: the first is that there should be adequate *anchorage* of unreinforced masonry wall to the diaphragm in order to prevent out-of-plane failure. The second is that the diaphragm should be *resilient* in order to allow yield displacement and an out-of-plane movement response. *Anchorage* and *resilience* require efficient connectors in order to transfer forces across the joint, (i.e., between the diaphragm beam and seismic force resisting system- the bearing walls). Pragmatically, builders of Umm el-Jimal employed a basalt corbel that is embedded in the masonry wall through creating a pocket in the masonry bearing wall for a depth equal to the same thickness of the wall or to its half. The corbel should act as a connector at the junction between the basalt diaphragmic beam and the bearing walls. The corbel can enhance the plastic deformation after the increased stress level produced by the seismic behavior. It allows a horizontal sliding movement during seismic motions and hence prevents the brittle failure of the basalt beam element. Utilizing the basalt material is also helpful because the connector should exhibit stiffness and yield strength in order to resist the diaphragm’s internal forces: a combination of tension, shear and fixture [45].

[5] Dry construction technique is also noticed in some walls using in the form of headers and stretcher (for more information see [30]).

[6] Interpretation for the exclusive use of flat apsidal church in Hawrān region is discussed by Al Rabady and Abu-Khafajah,[32].

[7] Dodge suggests that “[t]he Hawran was almost bereft of trees, so a different kind of architecture had to develop based on the use of stone for members usually made in wood - lintels, floors, balconies, even doors. Thus, the typical architecture of corbels supporting flat stone roofs, so well presented at Um el-Jemal emerged” [23].

[8] Butler suggests that this building was originally built as s large public audience hall consisting of an undivided nave and a broad apse without side chambers. It was converted for Christian service (i.e., as a church) after the promulgation of Constantine’s decree in 313 CE whilst conserving its pagan basilica plan. The semicircular apse is crowned by a half dome of concrete [4].

[9] It is also known as the levitating foundation that prevents the energy to pass through the system as it is absorbed by the isolation level.

[10] Howard Butler declares that he faced a problem in depicting the superstructures of Bosra Cathedral- the dome. He followed Melchior de Vogüé drawing (see *ill*.18: a restored section of Bosra Cathedral in [1]) and the design represented in the church of St. George at Zor'ah. Difference in depiction appears in the form of the central dome where de Vogue provided a relatively semicircular dome.

Conclusion

Post-earthquake anastylosis and reconstruction efforts remain dubious, especially in light that construction details are not being on sight and no accurate drawings are being available for ancient buildings. The study sought to tackle the uncertainties about possible structural systems used for roofing the apses in ecclesiastical architecture in Umm el-Jimal. Taking the case of Julianos Church, three theories are put forward; two of which are based on exiting reconstruction drawings available in literatures: the arcuated semidomical roof as suggested by Butler [14] and the flat roofing as suggested by Corbett and Reynolds [17]. A third theory is introduced in this study. It advances the apse as a buttressing system configured as a composite structure composed of two interrelated structural configurations: a nonstructural lightweight half dome used at the inner side of the apse and a corbelled relieving diaphragms that surfaced the outer part of the apse roof. The scattered evidence is variable enough to suggest that one definite roofing pattern existed in Umm el-Jimal. Thus, analyzing the roofing system in ecclesiastical apses in Umm el-Jimal could not advocate one theory over the other. Rather, our study adopts a holistic approach because we expect that it opens up at a new interpretation of the apses' structures that had been long discarded in Umm el-Jimal, as they are considered ancient and uncertain.

Although the study adopts a holistic approach, it should be justifiable to suggest that the least valid theory is that of theory two: the flat corbelled apse; advanced by Corbett and Reynolds [17]. Probably, Corbett and Reynolds sought to emphasize that builders of the Hawrān region maintained a corbelling culture. Nevertheless, and despite of the existence of large number of churches in Umm el-Jimal, there exists no single example that signifies for certain that the roofing style could have taken such a layered flat configuration. The first and third theories prove their relevance in this study because of the existence of pioneering examples in the Hawrān region. The composite theory is of particular interest because it suggests that the forms of church architecture could be rightly chosen for their symbolic meaning, yet, meanwhile, might have been automatically chosen because they are structurally the most appropriate, especially in regions endangered with natural hazards such as earthquakes and landslides. The *composite system* advances the attributes of the corbelling system as applied at apse compartments and highlights the importance of considering corbelling structures as relieving diaphragms. Failure to properly tie and anchor roofs and walls could limit their stability under both lateral out-of-plane loading and the in-plane load; leading to recurrent collapses and damages of the structure.

Diaphragms and their employment in Hawrān architecture have been previously discussed by Ignacio Arce. According to him, the diaphragm system is attributed with the Hawrān region in the early Islamic period and described it as a reinforcement technique. He traced the origin of the 'diaphragm arches' in the Hawrān region and described it as a system that consists of a transverse self-standing arch upon which a linteled or vaulted roof is overlayed. According to him, the concept of the 'diaphragm arches' could undoubtedly be related to the development of ribbed vaults (a crossing of two or more diaphragm arches- as the cross ribbed ceiling of Room 61 at Harane Place in Jordan which is considered the genesis of the ribbed vaults) [50]. The Relieving Diaphragm that has been addressed in this study furthers the knowledge about diaphragms in the Hawrān region during Late Antiquity and advances them as part of the seismic force-resisting system of archaeological structures. They are an engineering invention that adds a new dimension to the protection-based configurations in *seismicarchaeology*.

Conservation of demolished buildings in earthquake regions require accuracy of assessment models to evaluate the building's vulnerability and, hence, suggest the appropriate strengthening solutions. Unfortunately, detailed and accurate analysis of seismic performance of buildings in Umm el-Jimal, (and elsewhere in Hawrān) remain a challenge. In part, there is a paucity of information about the history of the building and its building techniques; the historical alteration (especially with the recurrent occupancy of the towns by successive groups and communities); the attributes of the building materials and the prevailing damages and their causes. In all cases, an accurate seismic assessment of the historical structures should consider that builders of Hawrān carried stone construction into the roofs of their structures. Such approach essentializes strengthening and stabilizing measures. It is anticipated that the future conservation efforts acknowledge these challenges and consider the unique roofing construction systems that have been long discarded in Umm el-Jimal and elsewhere within the Hawrān basaltic region. The theories introduced in this study can be a step in the right direction.

Declarations

- List of abbreviations: NA

- Availability of data and materials: data and materials are available via request ramarabady@hu.edu.jo

- Competing interests: The research does not involve potential competing interests.

- Funding: There is no funding party.

- Authors' Contributions: Rama and Shaher discussed the content and structure of the manuscript and the presented theories. Rama (the main author) wrote the main manuscript text, prepared the figures after discussing them with the co-author (Shaher Rababeh).

Both authors reviewed the manuscript.

- Acknowledgements: Our special thanks to the Department of Art and Archaeology of Princeton University for granting us permission to use Howard Crosby Butler Archive of Syria. We are thankful to

René Voorburg and Manuel Cohen for offering us permission to use pictures for churches from Syria. Architect Aseel Obeid helped in the drawings; for her we are grateful.

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Figures

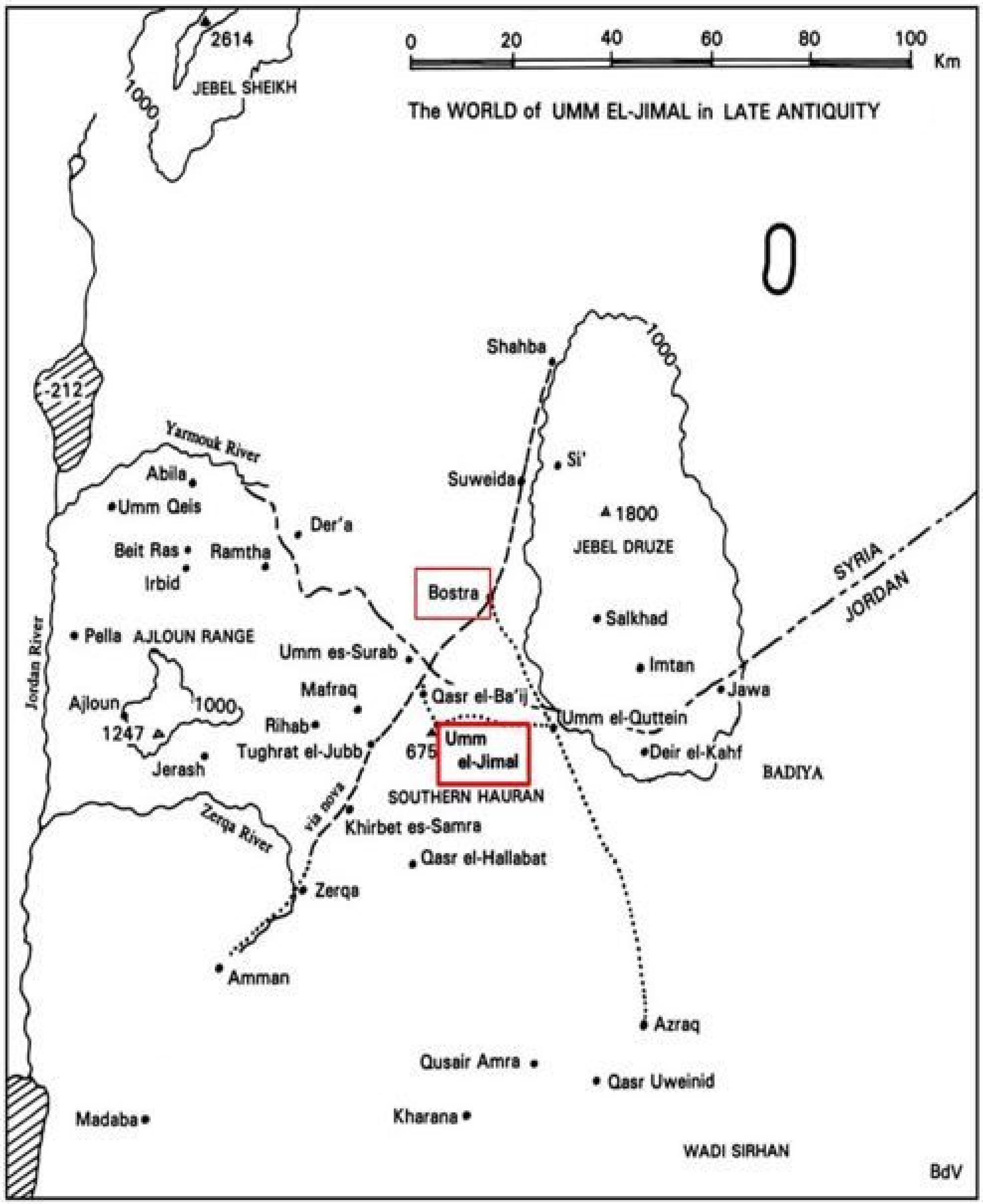

Figure 1

Map of Hawrān region during Late Antiquity; encompassing South Syria and North Jordan. Source: Modified from http://www.ummeljimal.org/en/drawings.html#prettyPhoto/2/.

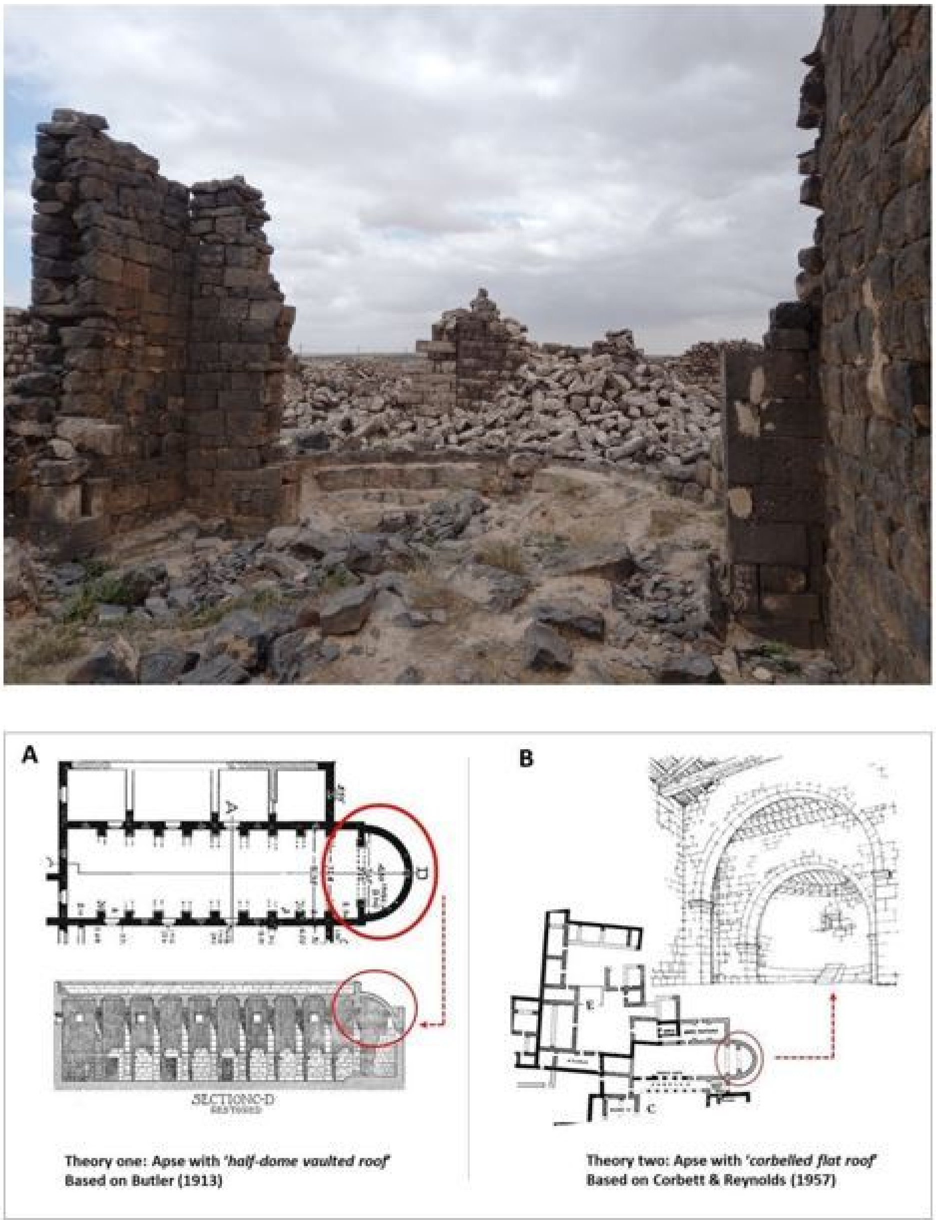

Figure 2

Demolished apse of Julianos Church in Umm el-Jimal (as it appears in contemporary time) and the theories for hypothesizing the roofing system(s) for the apse as illustrated by Butler [14]) and (Corbett & Reynolds [17]). (Source for the photo: ©The first author). Source for the figures of theory one (A): After ill. 147 and ill. 148 in [14]. It is a property of the Department of Art and Archaeology of Princeton University. It is used here after their kind permission. Source for figures of theory two (B): Modified from [17].

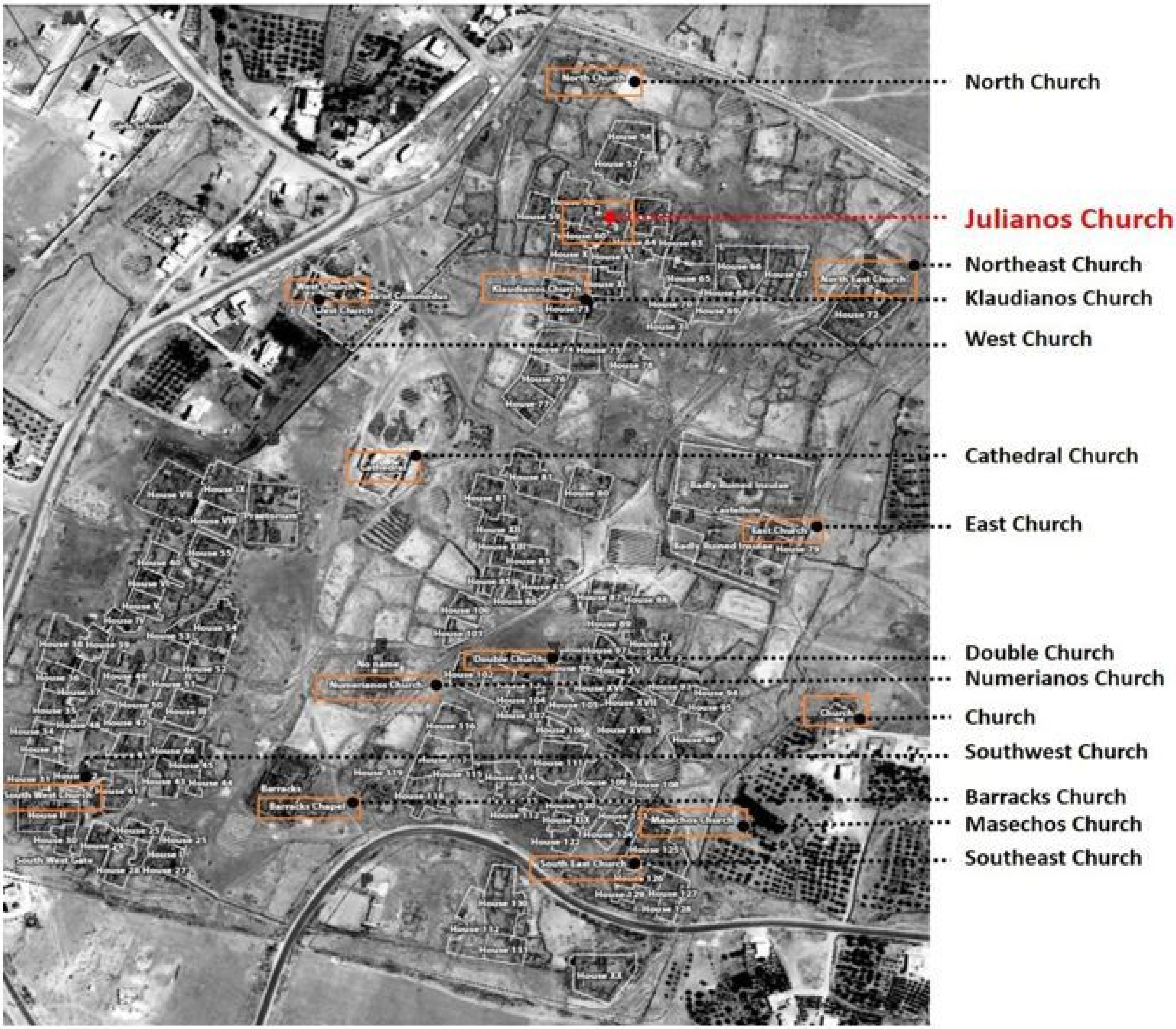

Figure 3

Umm el-Jimal within the Hawrān region in Late Antiquity; containing about fifteen churches distributed throughout a settlement grown from a farm town. Sources: Map of Hawrān during Late Antiquity: http://www.ummeljimal.org/en/drawings.html#prettyPhoto/2/.

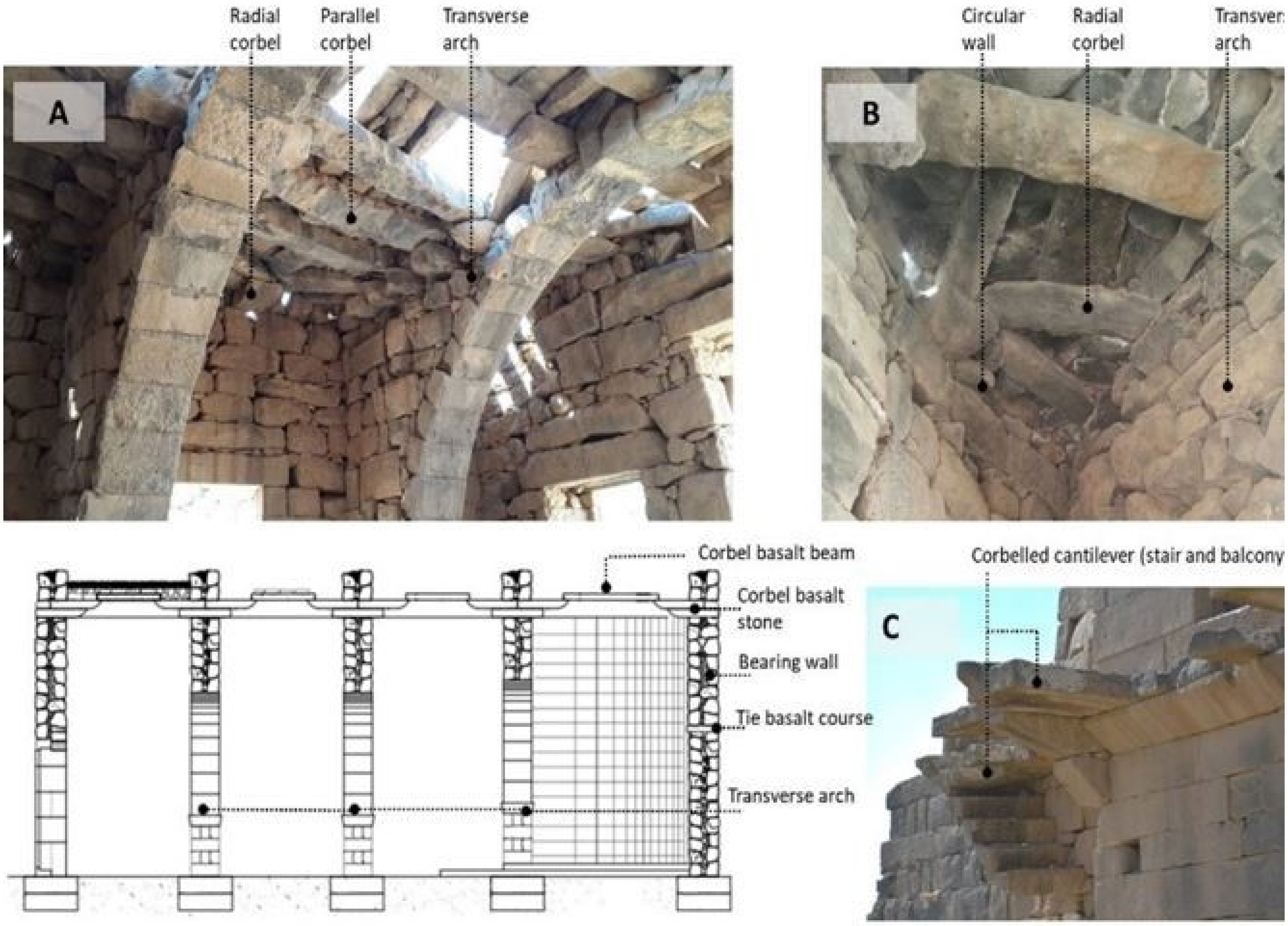

Figure 4

Using basalt stone as a building material for constructing load-bearing walls, transverse arches, and flat slab roofs. Parallel corbels in rectilinear compartments (A); web-shaped corbel in semicircular compartments (B); and corbelled cantilever (stair and balcony) (C). (Source: ©The first author).

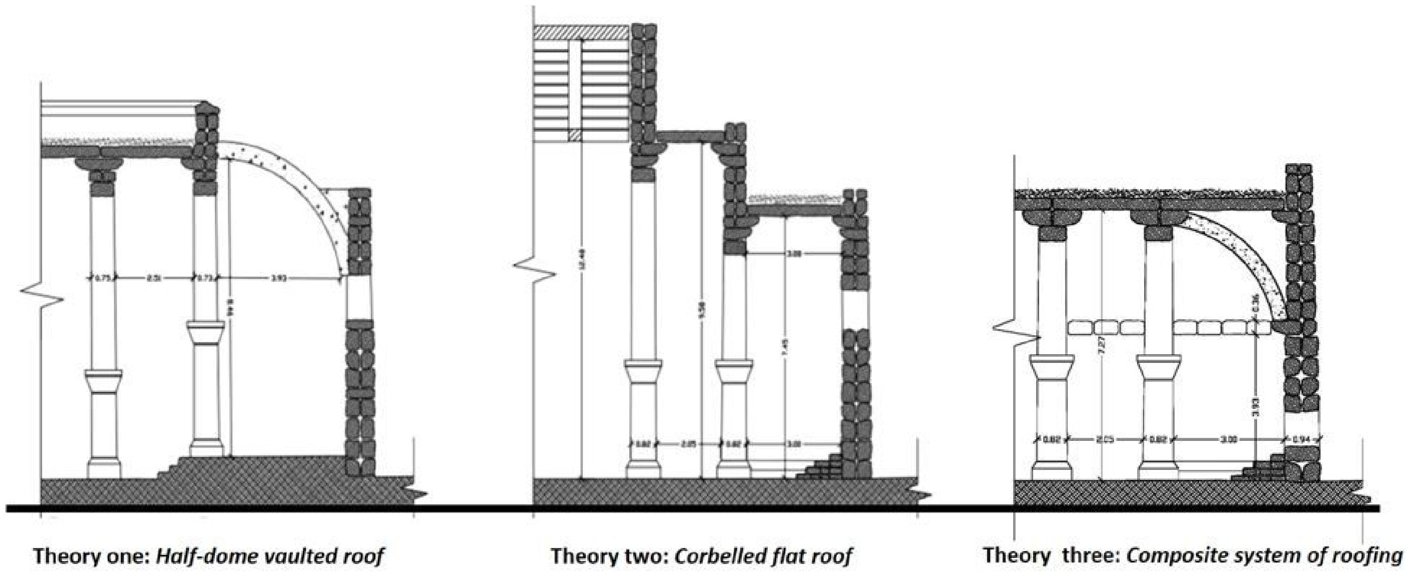

Figure 5

Three theories for anastylosis of roofing system for the apse of Julianos Church, Umm el-Jimal. Source: The first author.

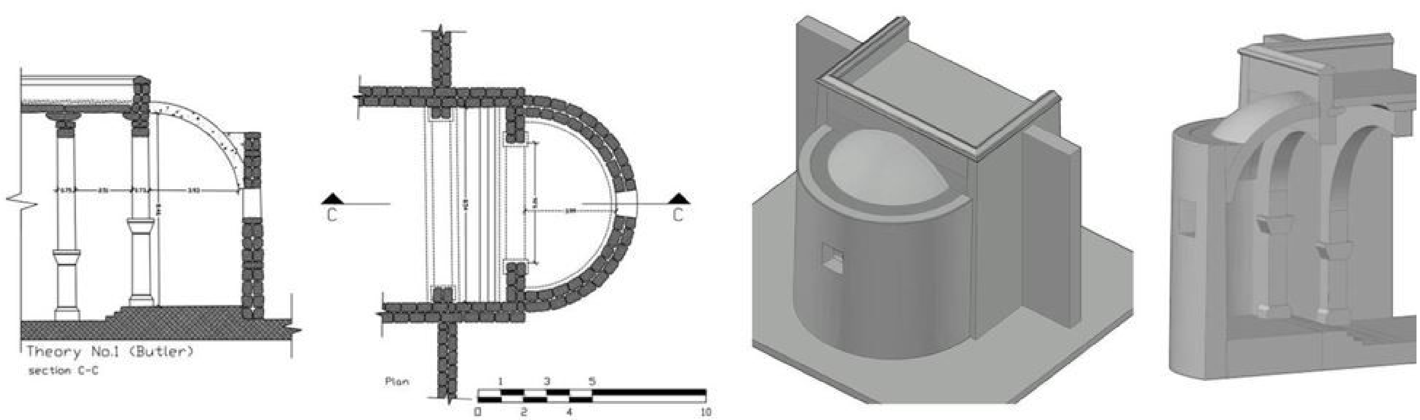

Figure 6

Reconstruction for Julianos Church in Umm el-Jimal with an apse sheltered by half-dome (Source: Section and plan, modified from [14]; Isometric and sective, the first author).

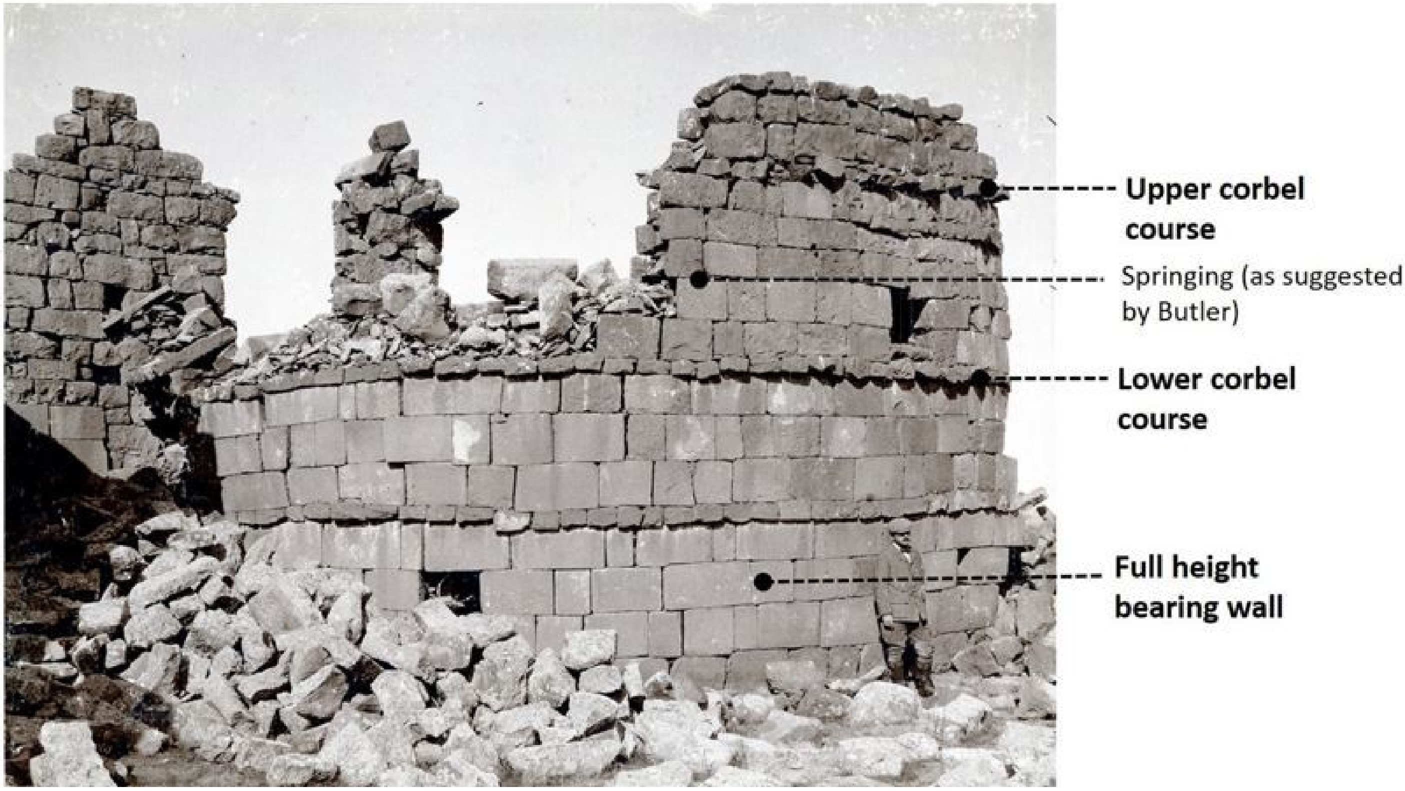

Figure 7

ill. 148 for the Apse of Julianos Church as it appeared in 1904-5 during Butler's visit to Hawrān. Sources: A: property of the Department of Art and Archaeology of Princeton University. It is used here after their kind permission.

Figure 8

Reconstruction for Julianos Church in Umm el-Jimal with an apse sheltered by flat corbelled roof. Source for the plan: after [17] ; Source for the section, Isometric and sective: the first author.

Figure 9

Adapted reconstruction drawings of Lubbēn Large Church built in 417 CE from Butler's illustrations. Plan and section are based on ill. 40 in [4]. Sective and axonometric are generated by the first author based on Butler's reconstructed plan and section along with ill. 359 in [15]. (Similar images could be also found in Al Rabady and Abu-Khafajah (Forthcoming)).

Figure 10

Bosrā South Bath depicted with a remaining compound system of semidome overlayed by straight basalt slab. Source: Livius.org: Articles on ancient history. Available on https://vici.org/vici/18076/*. Accessed in 29th September 2021.* The picture is a property of Livius.org; © CC BY-SA 3.0. It was captured by René Voorburg in 25th January 2014. It is used herein after his kind permission.

Figure 11

Basilica of Bosrā as depicted by Howard butler with a lightweight semidome that is attached to the wall of the nave directly atop the transverse arch (A) with the nave wall constructed of dressed basalt stone (B). Sources: The architectural illustrations are redrawn by the first author from ills. 236, 238 in [31]. The photo is a property of © Manuel Cohen. It is used herein after his kind permission.

Figure 12

Buttressing Apse as depicted by Butler for Bosrā Cathedral (A) and *by* de Vogüé for St. George Basilica in Zor'ah (B). Illustrations for Bosrā Cathedral (A) are redrawn by the first author based on *ill*. 248 and Plate XVII in Butler [31]; and illustration for Zor'ah Church (B) based on de Vogüé [2]. Source for photos is *Archaeological Archives,* accessed September 30, 2021, https://vrc.princeton.edu/archives/items/show/. The two photos are property of Department of Art and Archaeology, Princeton University. They are used after their kind permission.

Figure 13

A schematic reconstruction detail of the 'composite structural system' employed in the apse of the Julianos Church. The composite system incorporates (1) vaulted structure in the form of a half-dome composed of lightweight scoria bonded with mortar and (2) corbeled structure that appears in two forms: the lower corbel as a cantilevered ledge corbel for bedding a half-dome; and an upper cantilevered corbel at the top of the bearing wall acting as a relieving structure to prevent deformation in the half dome and apse wall. Source: the first author.