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Engineering the reconstruction of Hawrān's *Ecclesiae* during late antiquity: case of Julianos church in Umm el-Jimal, Jordan

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Abstract

This study challenges the stylistic-based classical prototype of the early Byzantine churches in the basaltic Hawrān region in the Middle East- the birthplace of Christianity and home to the world's most ancient Christian architecture and engineering ideologies. We focus on the engineering of the apsidal zone and its structural and architectural implications in relevance to the prototypical arcuated one. The instrumental case of Julianos Church in Umm el-Jimal provides an insight into the effect the local material and structural technique have on the formation of complex roofing structures for the apsidal zone. The detailed interpretation of the structural engineering reconstruction is coupled with historical research and digitally generated 2D and 3D reconstruction models. The findings indicate that the apsidal zone's engineering could have responded to Hawrān's unique material, structural techniques, and seismic measures. We finally compare the early twentieth-century scholars' stylistic-based interpretation of the apse roof to contemporary engineering-based reconstruction research based on historical evidence and contextual studies. Future researchers and conservators should consider a holistic approach that balances stylistic/engineering reconstruction processes carefully and numerically. The builders of Hawrān should have introduced novel engineering of their ecclesiastical architecture that differs from its 'classical' counterpart.

Keywords: Late antiquity, Buttressing apse, Composite structure, Relieving diaphragm, Antiseismic configuration, Hawrān

Introduction

Reconstruction of basaltic *ecclesiae* of late antiquity: debating the approach

The reconstruction of historic sites is usually configured through 'stylistic-based modules' representing their architectural and geometric formulation. The module is evident in archaeological sites exhibiting church architecture built during Late antiquity with unique building materials and structural systems. One of them is the basaltic Hawrān region in the Middle East- the birthplace of Christianity and home to its most ancient Christian architecture and engineering ideologies. The area presents many critical issues due to the poor state of conservation of the remaining architecture and the scarcity of documentation works conducted throughout the past decades. Many of these churches exhibit only the lower foundational courses- a matter that transforms the interpretation of the engineering works and their conservation even more complicated.

The difficulty in comprehending the scientific implications of Hawrān architecture was evident in the reconstruction modules set up by western researchers who visited the Syrian region shortly after the Ottoman Empire fell apart. Through significant documentary investigation, they tended to ascertain the original form of the existing buildings by 'stylistic-based reconstruction'. It is a method of comparing Hawrān structures to classical counterparts, with treatments, colors, and

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shapes conjectured to assure aesthetic consistency and architectural integrity. They didn't think about historic building engineering, which dealt with a wide range of locally sourced building materials, structural systems, seismic protection, and construction methods. "The physical property should be examined within the cultural context to which it belongs; not based on predetermined criteria," according to the ICOMOS Charter on "Principles for the Analysis, Conservation, and Structural Restoration of Architectural Heritage" [1]. As a result, each technique requires a unique explanation to accurately understand its structural performance and proceed with the best conservation intervention design. Structural systems in areas where hard igneous basalt and scoria are the only building materials, such as the Hawrān region and Cilicia in southern Turkey, should be of particular interest.

We believe that historical reconstruction should be approached differently. It is an engineering-based reconstruction that uses digital models of historic structures to establish a theoretical understanding of the reconstruction process. An engineering-based reconstruction allows us to hypothesize actual structural and engineering knowledge: the complicated structural system, the basic structural system, load-bearing, and lightweight elements, cross-sections, linkages, and bracing designs. We situate the 'Julianos Church' within the geometry of Hawrān's Late Antiquity churches, focusing on the apsidal zone, roof, and treatments [2]. The study proposes structural interpretations to challenge the Hawrān church architecture's stylistic-based classical exemplar. The church is divided into two sections: a rectangular open hall with transverse arches and a semicircular apse that runs the width of the nave. It is an excellent example of church engineering in Hawrān. Despite its poor condition of preservation, the apse has been discussed numerous times in the literature. Scholars proposed two stylistic-based reconstruction hypotheses for the roof of its apsidal region: a typical vaulted half-dome and an atypical corbelled flat slab. The current research examines two ideas about the images and drawings offered by their scholars. However, our field observations at the Umm el-Jimal archaeological site and significant historical research lead us to propose a third way of understanding Julianos Church's apse roofing structure. The study will now focus on three primary ideas concerning the roofing of Julianos Church's semicircular apse:

- Hypothesis 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 1904–1905.
- Hypothesis two: a *'corbelled flat roof.'* It is based on the reconstruction drawings provided by Corbett & Reynolds in 1957 in their study entitled "Investigations at Julianos' Church at Umm-el-Jemal."
- Hypothesis three: a *'composite system of roofing.'* This study suggests it. It is based on archaeological remains, comparative analysis with relevant examples, and contextual reading of ecclesiastical engineering in the Hawrān region.

The study uses digital tools to depict the three possibilities through a reconstruction procedure. The goal is to maintain a structure's sematic, communicative, perceptual, and cognitive values rather than its physical and architectural form; digital models help people grasp complicated information and convey and communicate existing or new knowledge [3–5]. Understanding the reconstructive context of 'objects' necessitates gathering all relevant information that uniquely identifies the entity and its creation and uses. Nonetheless, this engineering reconstruction should be founded on thorough "historical research" [4, 6, 7] that reveals similar engineering solutions considered by builders in the same region and period. It should also help us merge academic and practical knowledge by expanding our understanding of structures ([4: 56]). "Researchers risk confining research on items simply to their digitally reproducible properties" if the historical context is not taken into account while rebuilding heritage objects ([4: 50]). In archaeology, the problem is complex since the percentage of lost volumes exceeds what is saved, making it nearly impossible to reconstruct the past precisely. As at Umm el-Jimal, the information gathered in the field is insufficient to formulate a thorough theory. "It is required to stretch the critical hypothesis beyond and rely on additional records, testimonials, and comparisons that come from other similar situations" to overcome this shortfall ([3: 5]). As a result, models should be reconstructed using contextual and relational assumptions that connect the missing heritage to its original context while respecting its historical and aesthetic values and the compatibility and legibility of the original elements. The next part sets the scene for Umm el-engineering Jimal's history by introducing the city's principal building materials and structural systems.

Umm el-Jimal: city of volcanic building materials

The Nabataean (50-106 CE), Roman (106–300 CE), Byzantine (5th–early seventh century CE), Islamic era (661–900 CE), Druze who migrated southward from Syria (1905–1935 CE), and Mas'eid Tribe (1935–1950 CE) civilizations and inhabitants all arrived in Umm, el-Jimal. Because it was adjacent to Bosrā, the late Nabataean capital and later the capital of the Roman province of

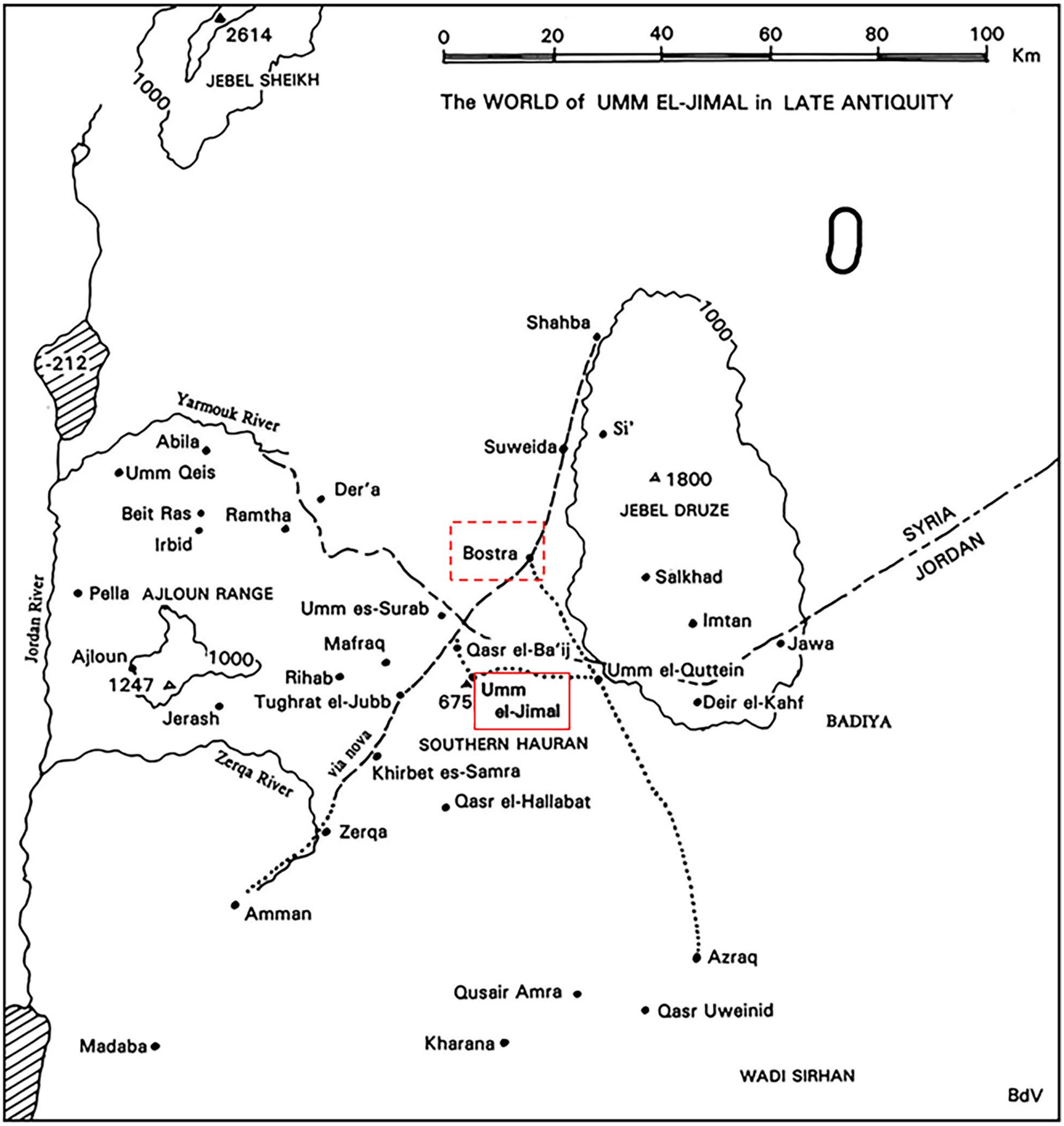

Fig. 1 Late antiquity map of the Hawrān region, including south Syria and north Jordan. Source: modified from http://www.ummeljimal.org/en/drawings.html#prettyPhoto/2/

Arabia, Provincia Arabia, local Nabataean nomads settled in Umm el-Jimal (Fig. 1). The village was created as a military station by the Romans, who also built a fort (castellum) [8]. During Late Antiquity, the city was a rural farming and commerce town with a population of 6000 to 8000 people, the majority of whom were Christians. As a result, the city saw a surge in church construction (about 15 churches) and around 150 domestic homes [9]. Buildings were constructed using only two volcanic materials: basalt stone and lightweight scoria.

Basalt

For construction and engineering, basalt stone is the most used building material. Volcanic eruptions in the

Jebel Druze erupted across the Hawrān Plain in Northern Jordan and Southern Syria between 15 million and 65,000 years ago, covering it with 300-m-thick basalt deposits. Basalt stone was often employed due to its availability and physical features [10]. Iron, magnesium, and other fine-grained mineral formations such as olivine, hornblende, and augite make up this complex, dense blue volcanic rock [10]. Furthermore, lava on the earth's surface may be fine-grained or porphyritic, comprising bigger crystals in a fine matrix or vesicular or foamy scoria due to rapid cooling [11]. Naturally, the physical and mechanical qualities of basaltic rocks utilized as the primary building material in historical buildings in the Hawrān region (including Umm el-Jimal) vary greatly depending on their source.[1]

The tension and compression strength of basalt stone prompted its usage as a load-bearing construction [11]. Because of its compressive strength, the builders constructed tall walls and raised their structures to two or three stories. Its structural strength was also utilized to pioneer cantilevering techniques, which involved projecting corbels for roofing from the walls [10]. Thin basalt slabs were set on the corbels and stretched to cover the roofs of single and multi-story buildings [10] and rectangular and semicircular compartments (Fig. 2). Because of its ability to withstand potential deformation and the thrust that generates horizontal pressure and lateral displacement is also used to construct framed constructions (lintels, beams, etc.) or transverse arches to support the roof. It was also utilized as cantilevers to create flying stairs and overhanging balconies.

Fig. 2 Construction of unreinforced load-bearing walls, transverse arches, and flat slab roofs using basalt stone as a building material. Corbelling is used in various ways: corbelled cantilevers, web-shaped corbels in semicircular chambers, and parallel corbels in rectilinear compartments (such as stairs and balconies). Source: private collection of Rama Al Rabady

Scoria

Local light materials, like volcanic scoria, were used to make vaulted roofs in apses. Dodge should have backed this theory because he claims that the Roman East's architecture interpreted Rome's using local materials and techniques [13]. While the lands of Hawrān do not have Roman concrete, he claims that builders in this region used light volcanic scoria as an alternative to the type used in Rome and Italy for vaulting techniques [13]. During the Roman period, when Hawrān came under significant Roman control in the early second century CE, and Bosrā was founded as the capital of the new Province of Arabia [13], they used it to construct vaults. The Roman baths in Bosrā were erected in the third century, and churches such as Bosrā Basilica and Bosrā Cathedral are examples.

Fortunately, we were able to locate some of the scoria-based lightweight mortar used to construct the dome of Umm el- Jimal's West Church. Khaled Al-Bashaire used archaeometry to investigate the mortar and figure out where the scoria came from. He discovered that the mortar is lime-based and hydraulic and that it contains basalt, grog, mortar remains, and charcoals in addition to the lime binder [14]. It differs from Roman-period mortar and cementing techniques, such as those discovered in the city of Geraca (Jerash, Jordan), which were made of calcic lime slaked with a small amount of water and containing natural aggregate sources such as calcite, gypsum, and quartz; or calcium, gypsum, and crushed pozzolana [15].

Although these studies are essential for estimating the age of structures, they do not provide insight into the lightweight scoria's structural performance and, as a result, engineering decisions. Light volcanic rocks, such

[1] In the Tertiary–Quaternary field of Harra El-Jabban, specifically from (the Umm Al-Qutein) area, local geologists conducted tests to investigate the geochemical, mineralogical, and magnetic features of the basalt stone. The presence of calcic plagioclase feldspar, pyroxene, olivine, iron oxides such as magnetite, ilmenite, and iron–titanium oxides (Titanium-augite, sphene) and spinel was discovered in the mineralogy of basalt [11, 12].

as scoriae, are thought to have been employed during the Roman period to lessen the weight of the vaults, so reducing the lateral strains on the buttressing walls and controlling the forces generated by the structure's parts [16]. Factors such as the availability of particular building materials, their structural behavior, and their qualities should be used to define structural treatments, building approaches, and, ultimately, the restoration process of church buildings with semi-circular apses.

Method and workflow

The study aims to use digital modeling and virtual reconstruction to depict three probable structural assembly processes in the apsidal zone of Julianos church. The reconstruction modeling approach and interpretation of the three underlying assumptions have been organized in four steps ([3: 10]), based on Pietroni and Ferdani's work:

- Data acquisition: the study uses both primary and secondary resources to support the theoretical reconstruction concerns. Both primary and secondary resources (in the form of existing materials, evidence, and testimonials on the site) were used to support the theoretical reconstruction concerns (in the form of interpretive studies based on literary, cultural patterns, comparisons, etc.) [5]. The information gathered includes archaeological evidence from nearby areas, the graphic acquisition of Julianos church in its current condition of preservation, published written documents, architectural designs, images, illustrations, and published written documents. The study also looked for similar archaeological cases in the Hawrān region and released graphic evidence that gives similarities and logical implications for interpreting our case's structural and architectural rationale: Julianos Church.
- Data processing: three hypothetical reconstruction models were created, two of which were based on published literature and the third was developed in this study by taking into account elements that were documented but are no longer available on site, figurative deductions, typological comparisons, and cultural patterns of structural technologies used during the construction period [3]. Data was gathered and analyzed in partnership with archaeologists and civil engineers to develop reconstruction recommendations for current cases and patterns, mainly when it came to seismic measures.
- The creation of 2D and 3D reconstructive hypotheses: the current condition of Julianos church has various components that do not correspond to its initial stage of construction compared to previous pictures. The study presents hypothetical reconstruction models that could be used for illustration purposes, i.e., to grasp the construction logic of the reconstructed Julianos church theoretically (rather than numerically) and provide a possible convincing explanation of the church's final architectural style. On the other hand, Reconstruction models should be used with caution for interpretative and analytical reasons [3]. These models should be minimalistic, and their scientific (technical) elements should be integrally synthesized into a visual representation to be most effective. A load-flow depiction that positions the loads, their typologies, and their influence on the building were required in addition to the 3D reconstruction hypothetical models.
- Source mapping and transparency: many sources and references were combined to create three-dimensional virtual models for the three hypotheses. The data was organized, deductively examined, and synthesized to develop the hypothetical reconstruction models. Furthermore, all data was mapped and cited to make the reconstruction process visible.

Analysis and discussion

The semicircular apse of Julianos church: hypotheses for its engineering systems

Even though Umm el-Jimal has fifteen Late Antiquity churches, no one example specifies what roofing materials or building techniques were utilized, particularly in the apse zones. Apart from buttressing and wall thickness indicators that could specify the employment of a particular roofing system, the materials used for the apses in Umm el-Jimal have left remnants that could be used to infer prospective building materials or techniques employed in the apse (Fig. 3). Stylistic-based restoration and engineering-based reconstruction are being studied to restore Julianos church to its original state of conservation. Different theories could be developed based on these approaches to explain the interaction between design decisions, building materials, and structural systems.

Stylistic-based reconstruction

Earlier scholars explained the relationship between design decisions and the final architectural style of Julianos church through stylistic-based reconstruction that encompasses two hypotheses: a typical arcuated apse and an atypical flat apse.

Hypothesis one: apse with a half-dome vaulted roof.

Stonemasons never used the circular plan in Umm el-Jimal. The majority of their planning was rectilinear. During Late Antiquity, an idea for incorporating the semicircular apse as an architectural feature in church

Fig. 3 Remains of the original apse of Julianos Church in Umm el-Jimal- the foundational courses of the apse wall with parts of the Synthron (as it appears in contemporary time). Source: private collection of Rama Al Rabady

buildings emerged. In Umm el-Jimal, Howard Butler identified apses of churches and chapels, all of which had half-domes, including Julianos Church (Fig. 3) [17: 175]. The reconstruction drawings for Julianos church are shown in Figs. 4 and 5. They are based on Butler's section and plan in *ill.* 147 and *ill.* 148 ([17: 175, 176]).

A semicircular apse with a radius of 3.80 m and a height of 8.48 m is depicted in the drawings. The semicircular wall has a thickness of 73 cm. It has a window with a height of 3.9 m, directly above which the half-dome is positioned. The arch of the half-dome is approximately 50 cm thick. The materials for constructing the half-dome are not identified in Butler's original designs. Furthermore, the half- dome's connection to the apse bearing wall is unknown (abutment). The bottom of the half dome is slightly protruding from the wall from the inside. As a result, the reconstruction work (Figs. 4 and 5) falls short of depicting the half-dome logical structural behavior. If we believe that the builders employed scoria bonded with mortar to make monolithic lightweight vaults, then Butler's half-dome idea might be discussed.

When Butler visited Umm el-Jimal in 1904–5, he stated the following about Julianos church: "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*" ([17: 173]) (emphasis is added). His description, however, does not always match the scene he recorded on his camera during his visit (Fig. 6). The wall is partially dismantled and stretching to its full height and width at the northern section of the picture, which shows a view from the southeast of Julianos Church's apse. The wall is made up of two stone skins filled with rubble.

The structural behavior of a vault system, including domes and half-domes, is discussed by Lynne Lancaster [20]. Forces acting in both curvature directions are common in domes: meridional and circumferential hoop forces. Because circumferential hoop pressures are turned into hoop forces that can change from compression to tension in the haunches, they threaten the dome's structural stability. The strength of the structure is theoretically determined by the abutment's breadth and height [20]. Controlling the materials' weight helps reduce the impact of hoop tension on the haunches. The lighter the materials at the crown and the heavier the materials at the sides, the more probable the dome will be able to reorient them downward onto the abutment to resist the lateral thrusts [20]. In other words, it lessens the gravitational effect. The ability of the abutments to resist the lateral force induced by the half-dome is also critical. Such a sequence in structural behavior could not be essentially traced in the apse of Julianos Church, according to Butler's half dome idea. In truth, the apse wall was preserved to its full height, with no evidence of its prior use as a half-dome supporting. Furthermore, the wall retained its whole thickness. As a result, it does not have a recess suggesting a half-dome bedding ledge, as shown in Fig. 6.

Butler's photograph does not verify that the half-dome was placed on a wall abutment that secures its structural stability. In fact, there could be little doubt about the accuracy of Butler's description and the restored drawings that show the apse side of Julianos church and a cut through it. Nevertheless, John Wilkinson warns us to be cautious with Butler's documentary work in Syria. He tended in his study "What Butler Saw" to question the reliability of the observations and measurements made by Butler during his expeditions to Syria [21]. A significant concern about 'imperfections' is because Butler's work contained errors in measurements (in comparison with recent surveys) and simplified methods of measurement that excluded triangulation and diagonal measurements. Indeed, the imperfections lie not only in size 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, the hypothesis 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. The corbelling culture invites us to discuss a second apsidal roofing hypothesis introduced by Corbett & Reynolds in 1957- a flat basalt roof.

Hypothesis two: apse with a corbelled flat roof.

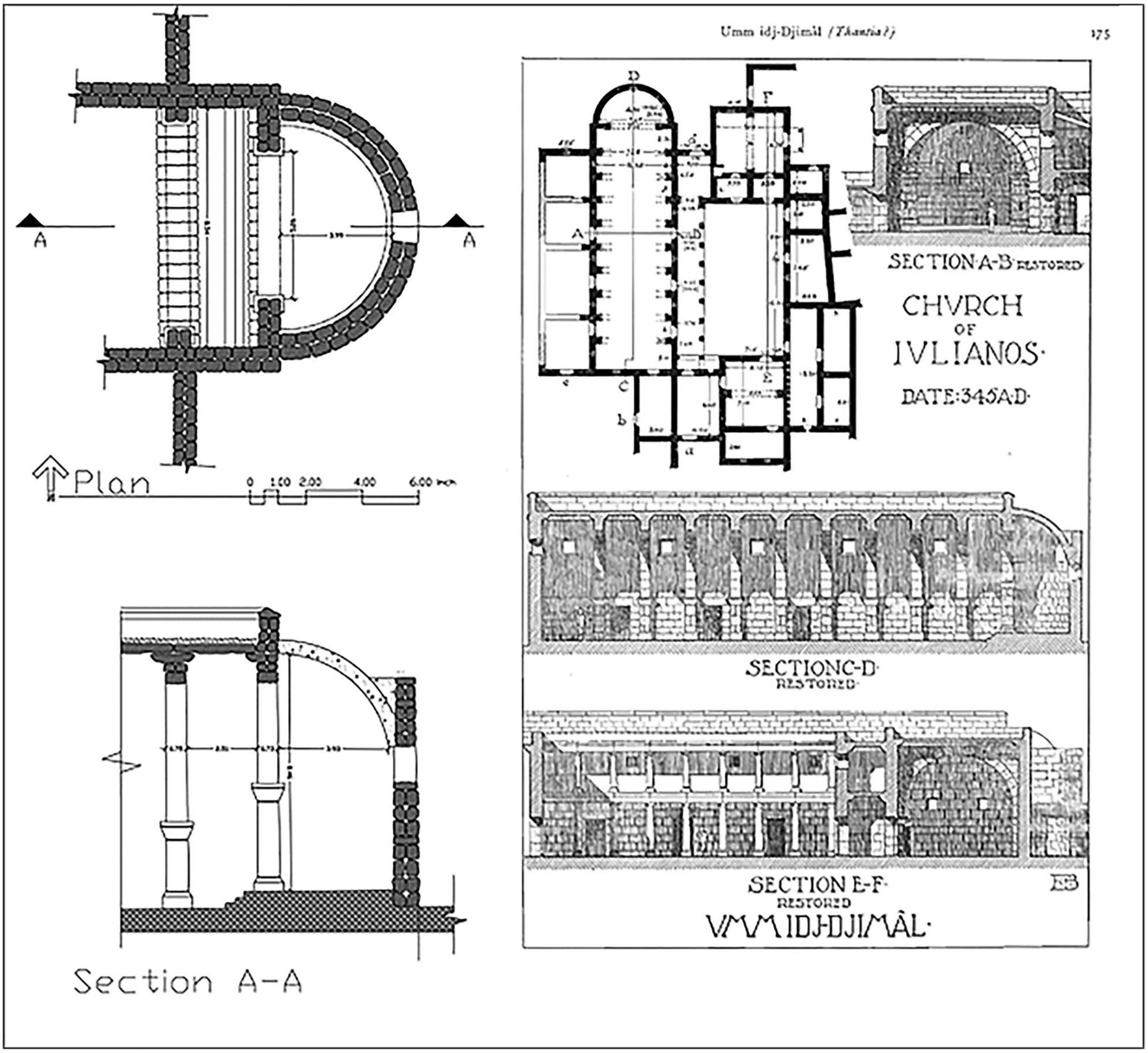

Fig. 4 Digital two-dimensional redrawing of Julianos Church apse (left) similar to *ill.* 147 published in ([17: 175]) (right- image as in the original)

Builders of church architecture in Umm el-Jimal have developed new skills in structural engineering and building techniques because they were familiar with the qualities of the sole type of stone available: basalt. As a result, corbelling systems were used extensively in construction.

The cantilever principle is used in corbelling [22]. It's a full-fledged structural system with "cantilevering long, finger-like stones in a wall [act] as ledges on which stone beams are then placed to create a ceiling or roof" [(10: 18]). Horsfield also defines 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" ([8: 458]). In this case, long slabs of basalt were resting on corbelled courses. Larger spaces were solved by incorporating transverse (or girder) arches [9] (Fig. 7). Hence, it is called the '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 laid dry ([13: 224, 229]). This means that building stability and sustainability are dependent on the actual mechanisms of the techniques involved in building these structures. Several church halls exhibit monumental transverse arches attached to internal buttresses to take the thrust of the arches and transform it into the ground [8].

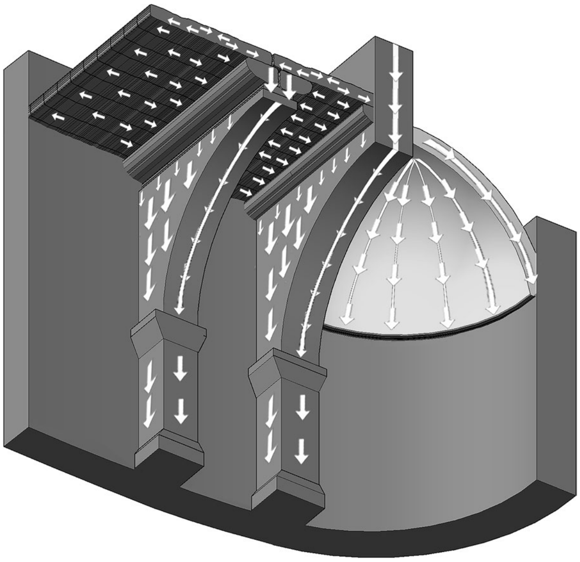

Fig. 5 Drawing of the structural system according to theory one showing the compressive forces flowing through the structure with the building materials and structural elements used

Fig. 6 *ill.* 148for the Apse of Julianos Church as it appeared in 1904-5 during Butler's visitto Hawrān. Sources: A: property of the Department of Art and Archaeology ofPrinceton University. It is used after their kind permission

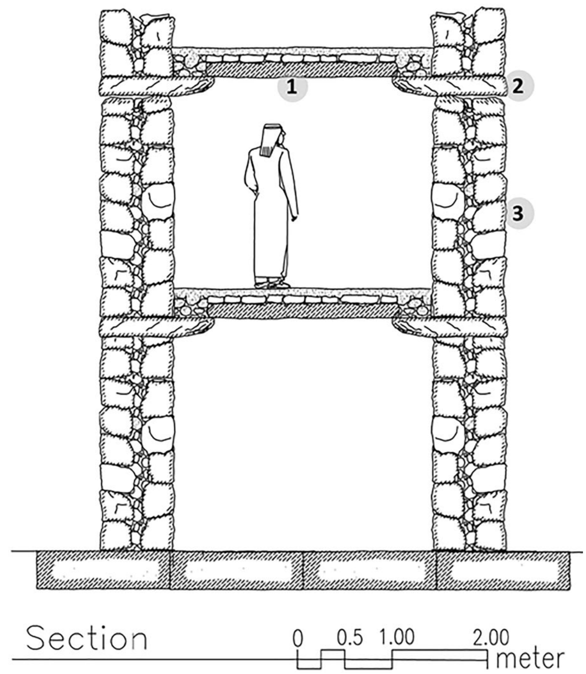

Fig. 7 Corbelling system for generating load-bearing flat roofs in Umm el-Jimal

Realizing the capabilities of basalt stone in constructing flat roofs along with the existing remains of transverse arches, Corbett and Reynolds provided reconstruction drawing in the form of 2D drawings (plan) and 3D drawings (manual interior perspective) depicting the roofing system for the apse in Julianos Church with the flat double-corbelled roof resting on the transverse arches and covering the entire apse at two different levels (Fig. 8) [19]. Basalt is used in building the top as a dry construction technique (stones with no mortar joints). It differs from the wall construction techniques, most of which were constructed with basalt masonry and filled with rubble and lime mortar.[2] 2D reconstruction drawings for the plan and a hypothetical section are illustrated in Fig. (8), and a 3D reconstruction model is hypothetically generated in this study based on the pictures provided by Corbett and Reynolds (Fig. 9).

Fortunately, there exists a notable 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 with a corbelled flat slab structure (*ill.* 144 in ([17: 168])). Another regional example of the employment of the flat structural technique appears in Lubbēn- an ancient village in el-Ledjā, Hawrān. When Butler visited Lubbēn, he observed its two *aula ecclesiae*; the Large Church and the Small Church (the Chapel- Fig. 10)), and seemed astounded 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" [24]. Similarly, the apse in the Chapel is "roofed using a corbel course set upon an in-curving

[2] The dry construction technique is also noticed in some walls using headers and stretchers (for more information, see [23]).

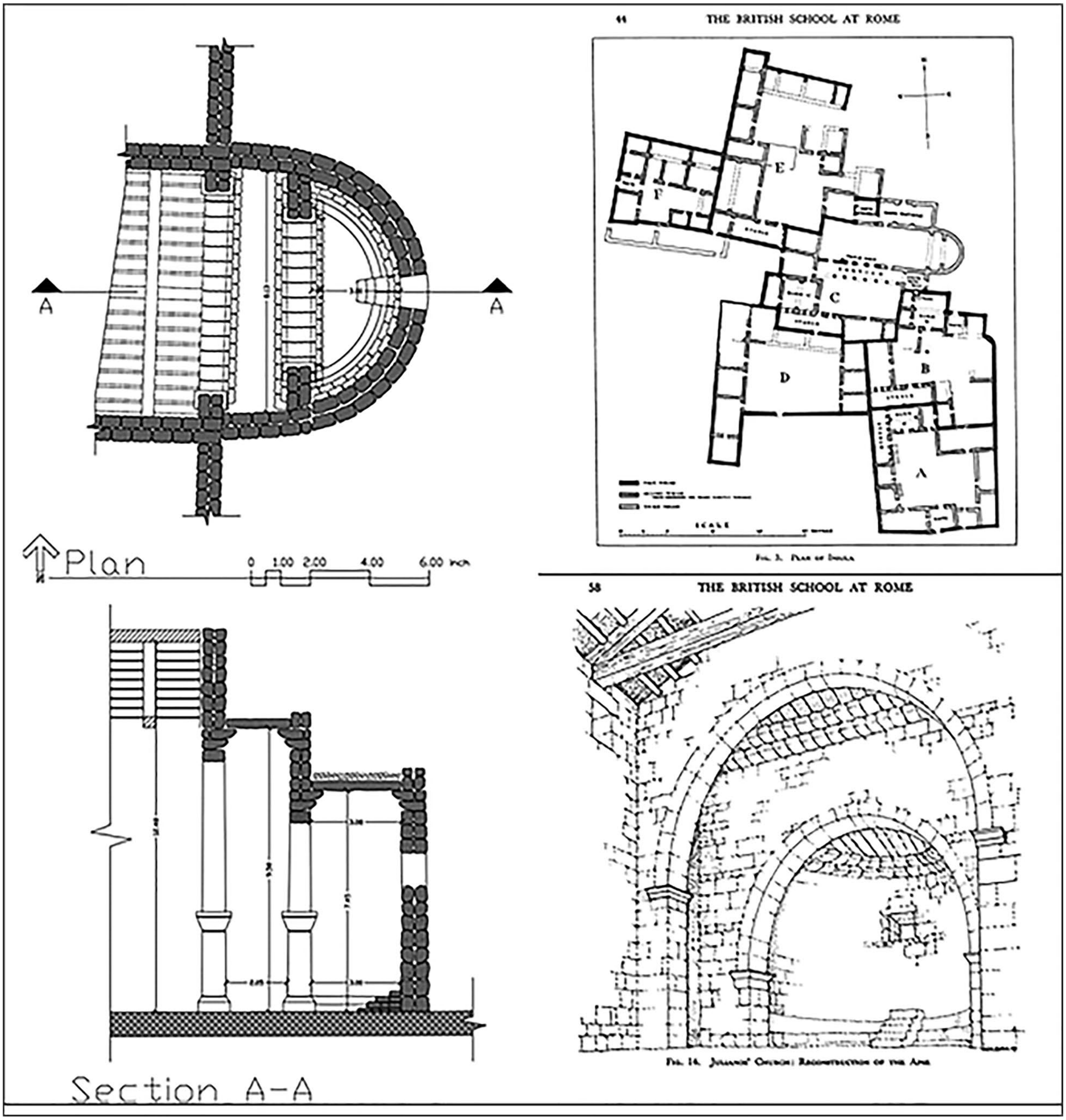

Fig. 8 Digital two-dimensional redrawing of Julianos Church apse (left) similar to Figs. 3 and 14 published in Corbett and Reynolds 1957: 44, 58 (right- images as in the original)

wall and carrying slab" [24]. Butler's documentation of the Large Church shows the flat-roofed apse that resulted from using the corbelling system supported by transverse arches (Fig. 10).

Although there exist real examples that support the 'flat roofing' hypothesis for sheltering the apse in Julianos Church, it is still uncertain if we could generalize this structural hypothesis to all churches in

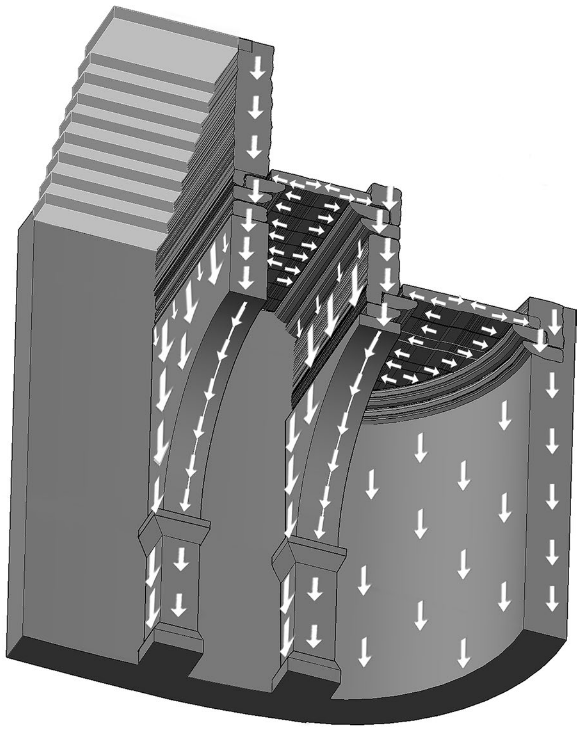

Fig. 9 Drawing of the structural system according to theory two showing the compressive forces flowing through the structure with the building materials and structural elements used

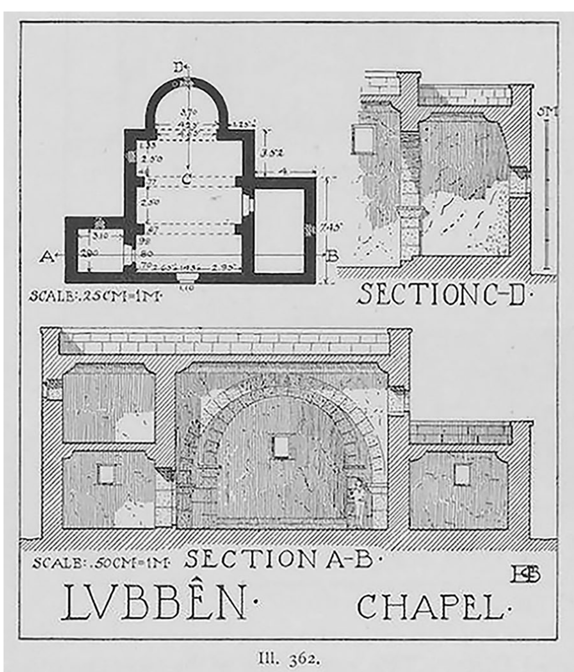

Fig. 10 *ill.* 361- reconstruction drawings of Lubbēn Large Church built 417 CE from Butler's publication ([26: 418])

Umm el-Jimal or other areas within the Hawrān region. Nevertheless, it is worth noticing that 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 (Fig. 10).[3] However, a similar treatment is not noticed in the case of Julianos Church, where Corbett and Reynolds depicted the roof of the nave with a pitched wood structure, as seen in Fig. 8.[4] Besides, it should be sensible to approach Julianos Church through the fundamental environmental factors that accompanied the early settlements of Christian people in the volcanic Hawrān region- the region most vulnerable to natural hazards of earthquakes and landslides.

Engineering-based reconstruction

Because of their history, materiality, and construction, structures in cultural heritage buildings pose numerous conservation issues [7]. As a result, research into these structures is being pursued as a scientific subject with an interdisciplinary approach to ensure the "integrity of all its components as a unique product of the specific building technique of its time" [1]. A thorough understanding of structural behavior and material features techniques employed in the initial and early stages of construction is fundamental [1, 7]. Instead of examining the building's components and individual elements, these characteristics should be understood by looking at it as a whole structural system. A hybrid approach combining corbelling and arcuated structures is proposed as a third option for engineering the apse in Julianos Church.

Hypothesis three: Apse with a composite system of roofing (corbelled roof and lightweight arcuated semidome).

A central case to consider when tackling the monumental structures in the Hawrān region is the South Bath of Bosrā, built between the second and third centuries [26]. According to its current status, the roofing system in this building is depicted with two layers: a lightweight arcuated shell and a flat corbelled basalt slab (Fig. 11). A unique roofing style invites us to advance a third hypothesis for examining the roofing of church structures in Umm el-Jimal: a *'composite system of roofing.'*

Structures in Hawrān are based on a corbelled buttressing system; buildings are constructed with nonreinforced load-bearing masonry walls and transverse arches

[3] . Interpretation for the exclusive use of the flat apsidal church in the Hawrān region is discussed by Al Rabady et al. in [25].

[4] Dodge suggests that "[Hawrān] 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" ([13: 35]).

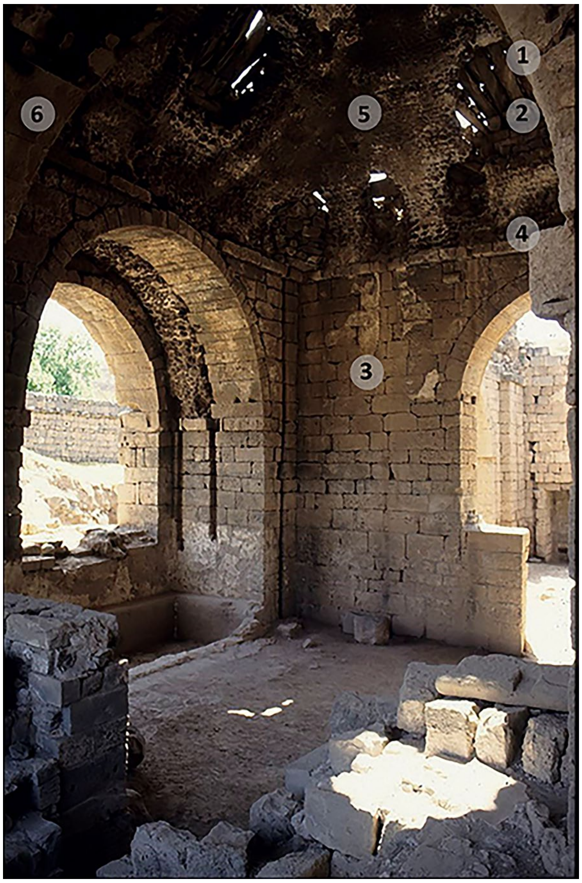

Fig. 11 Bosrā South Bath is depicted with a remaining compound system of semidome overlayed by a straight basalt slab. Source: Livius.org: articles on ancient history. Available on https://vici.org/vici/18076/. . It was accessed on September 29, 2021. The picture is a property of Livius.org; ©CC BY-SA 3.0. René Voorburg captured it on January 25, 2014. It is used after his kind permission

(girders) that support flat corbelled roofing slabs. The 'buttressing; ideology is also used to strengthen structures incorporating arcuated compartments prone to damages caused by static and dynamic forces. Buttressing is noticed in the cases of Bosrā Cathedral, built 512–3 in Bosrā, and St. George Basilica, Zor'ah, built 515 CE [1, 29] (Fig. 12). Reconstruction drawings and photos provided by earlier scholars (Butler and de Vogüé) represent the church building with what Butler termed as '*buttressing apses*' (Fig. 12)[5] [2, 18]. The *buttressing apse* is suggested as a 'strengthening' and 'stabilizing' element for church architecture constructed in the Hawrān region. Since the central dome is built as an unreinforced lightweight structure, it is suggested that the hemispherical apse can perform a 'buttressing' role.

However, buttressing performance necessitates a surcharge above the haunches and the construction of a lateral thrust-resistant abutment [20]. The ability of the abutments (in our case, the apsidal bearing wall) to resist lateral thrusts is determined by (1) abutment thickness and (2) abutment height, according to Lancaster [20]. Furthermore, modifying the abutment measurement or reducing the weight that creates the surcharge above the vault has an impact on the entire system's stability (such as mortared rubble fill). As a result, a substitute reinforcing mechanism is unquestionably required.[6] The photo of the remnant apsidal wall taken by Butler on his visit to the region can assist us in further investigating the composite hypothesis and demonstrating its process (see Fig. 7). In the photo, the remaining apsidal wall is at full height, interrupted by two tiers of projecting corbel courses. Based on these structural elements, Fig. 13 shows a three-dimensional reconstruction drawing of Julianos Church's buttressing apse as a "composite system of roofing".

According to this composite hypothesis, a lightweight half-dome of volcanic scoria and cement rests on a row of cantilevering stones in the apsidal wall (ledges) (the lower corbel in Figs. 7 and 13). Another layer of load-bearing structure should have been constructed to take off the forces and protect the lower half dome. The corbelled structural layer could be regarded as a Relieving Diaphragm. The first role of diaphragms is to transmit static and dynamic forces horizontally and provide a continuous load route for the static and seismic details. The second is to connect the structural parts so that they can resist lateral stresses comprehensively, i.e., it guarantees the structure's box-like effect during a dynamic movement.

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

[5] Howard Butler declares that he faced a problem in depicting the superstructures of Bosra Cathedral- the dome. He followed Melchior de Vogüé's drawing (see ill.18: a restored section of Bosra Cathedral in [27] and the design represented in the church of St. George at Zor'ah. The difference in depiction appears in the form of the central dome, where de Vogue provided a relatively semicircular dome.

[6] Essentially, resistance to earthquakes has formed an 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 their landmark book '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 [34]. 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 ([30: 201]).

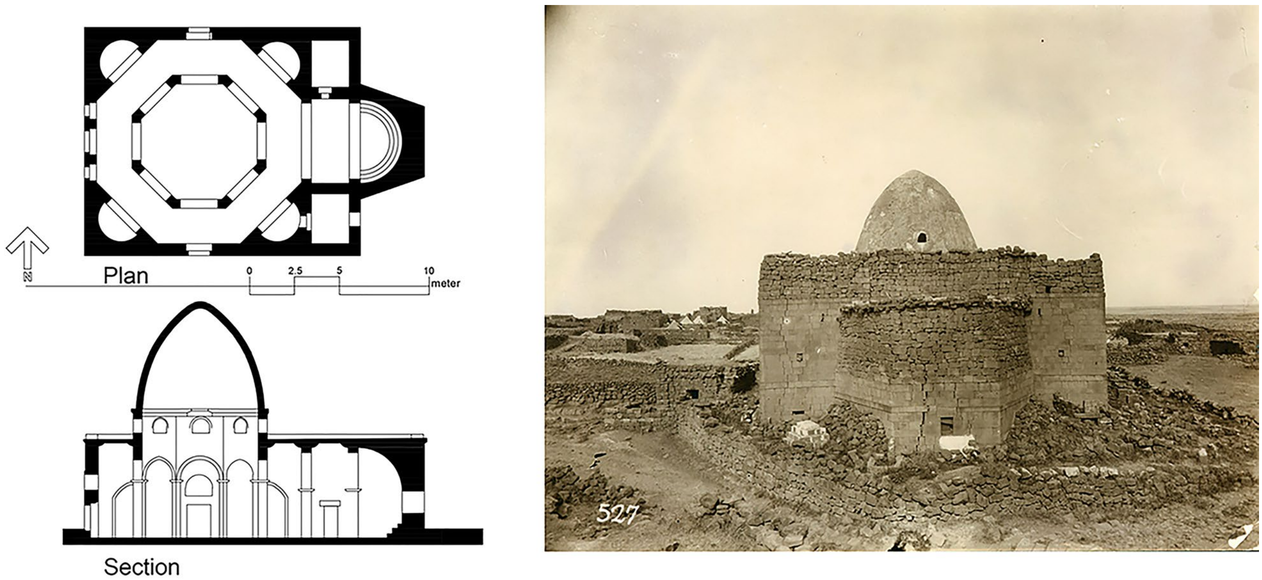

Fig. 12 *Buttressing Apse* depicted by de Vogüé for St. George Basilica in Zor'ah. [2]. The source for the photo is Archaeological Archives, accessed September 30, 2021, . The photo is a property of the department of art and archaeology, Princeton University. It is used after their kind permission https://vrc.princeton.edu/archives/items/show/

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[7] (Fig. 13). The monolithic half dome acts as a lightweight 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. In addition, it provides a 'safe' thrust domain for the lightweight half dome, especially under lateral movement.

Seismic buttressing of Relieving Diaphragm through 'tying and anchoring':

Umm el-Jimal was well known to be subjected to periodic earthquake jolts and a catastrophic earthquake in 747 CE that destroyed the town. It is difficult to believe that the builders used heavy masonry basalt stone to construct the roofs of their buildings without considering antiseismic engineering in the volcanic Hawrān region. Building engineering at Umm el-Jimal should have addressed specific earthquake prevention techniques. After all, earthquakes frequently cause roof structures covering ancient churches to collapse. The roof is principally responsible for demolishing the underlying masonry structure, resulting in total devastation. There are two sorts of damage mechanisms [30]. The first occurs in the nave portion in a transverse direction, where the roof's collapse is frequently followed by the collapse of the nave wall (or the clerestory).

The second happens along the navel's longitudinal axis (also known as transversal motion). Unreinforced roofs have reduced stiffness in this direction, generating out-of-plane bending by pushing the top of the nave wall with horizontal inertia force. Under the seismic motion, the nave wall experiences significant displacement, resulting in roof collapse and extreme deformability that impacts the apse. As a result, the apse façade's out-of-plane channel collapses. The failure of the church construction to resist seismic motion is linked to two elements in both cases [30]. The first is roof behavior; the construction method plays a crucial role in initiating (or preventing) the emergence of a damage mechanism. The second problem is a lack of linkages between vertical planes and between the apse's roof surface and the walls, as seen in most ancient structures where each segment's borders were erected individually [30]. Better connectivity between the various planes of the system (horizontal and

[7] Examination of its geological formation will show that Umm el-Jimal has certain geological peculiarities which are not common in other cities. The rocky surface makes a firm and suitable basis on which to build. The rock could be used and practically no foundations were necessary, other than leveling the surface when the site on which a building was to be constructed was on a slight slope. The goal was to achieve consistent resistance to subsidence. Therefore, the foundations were built directly on the leveled bedrock with the same width as the wall.

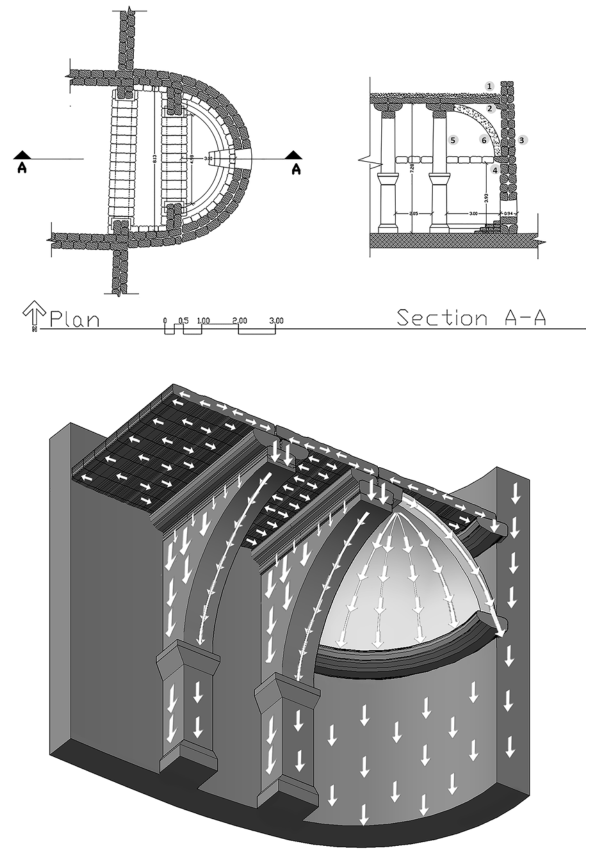

Fig. 13 Drawing of the structural system according to theory three showing the compressive forces flowing through the structure with the building materials and structural elements used

vertical; walls, floors, and ceilings) is one of the most significant variables for increasing the seismic safety of nonstructural masonry structures in recent research (see, for example, [29, 33]).

The employment of a load-bearing diaphragm transforms the apse into a buttressing structure that strengthens the seismic response of the building. According to Sathiparan, diaphragm construction should consider two conditions: the first is that there should be adequate *anchorage* of an unreinforced masonry wall to the diaphragm to prevent out-of-plane failure. The second is that the diaphragm should be *resilient* to allow yield displacement and an out-of-plane movement response. *Anchorage* and *resilience* require efficient connectors 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 by creating a pocket in the masonry bearing wall for a depth equal to the same thickness of the wall or to its half (Fig. 14). The corbel should connect the

Fig. 14 Load-bearing corbel built of basalt anchored into the wall with a dry construction technique that allows yielding lateral movement. Source: private collection of Rama Al Rabady

diaphragmic basalt beam and the bearing walls. It could have allowed a horizontal sliding movement during seismic motions and hence prevented the brittle failure of the basalt beam element. Utilizing the basalt material is also helpful because the connector should exhibit stiffness and yield strength to resist the diaphragm's internal forces: tension, shear, and fixture [29].

Results

Reconstruction efforts are suspect, especially given the lack of construction details and the lack of accurate drawings for historic structures. The research goal was to address the unknowns surrounding possible structural systems for roofing the apses in ecclesiastical architecture in Umm el-Jimal. Three hypotheses are proposed for Julianos Church (Fig. 15); two of which are based on stylistic conceptions of church architecture: the arcuated hemispherical roof submitted by Butler [17] and the flat roofing proposed by Corbett and Reynolds [19]. This study introduces the third hypothesis. It presents the apse as a buttressing system composed of two interrelated structural configurations: a nonstructural lightweight half dome used on the inner side of the apse and corbelled relieving diaphragms that surface the outer part of the apse roof. The evidence is inconsistent enough to suggest that Umm el-Jimal had one distinct roofing pattern. Thus, studying the roofing system in ecclesiastical apses in Umm el-Jimal (and the Hawrān region in general) during Late Antiquity could not support one hypothesis over the other. Instead, we took a holistic approach because we believe it will lead to a new understanding of the apses' structures, which have long been overlooked in this region due to their age and uncertainty.

Although the study advances a holistic approach to historical reconstruction, it should be justifiable to suggest that the least valid hypothesis is the second one: the flat corbelled apse, promoted by Corbett and Reynolds

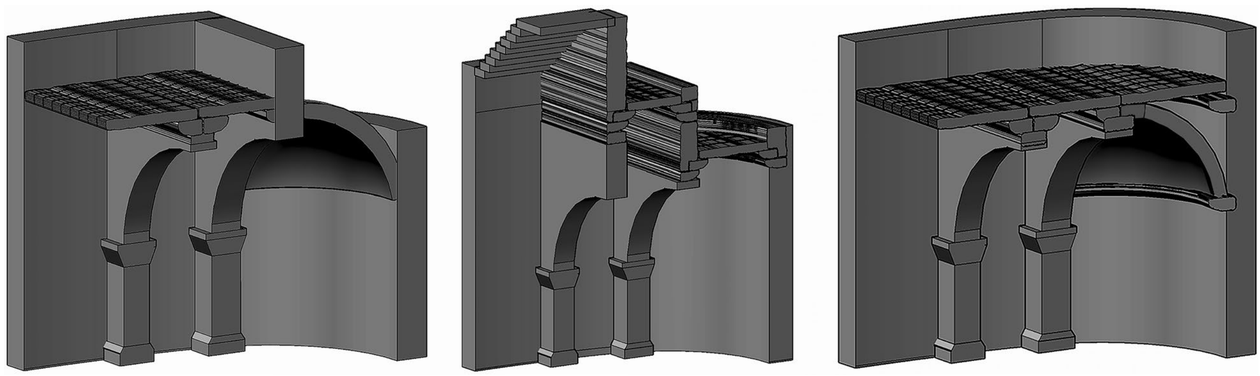

Fig. 15 Three hypotheses for the reconstruction of the roofing system for the apse of Julianos Church, Umm el-Jimal

[19]. Probably, Corbett and Reynolds sought to emphasize that the builders of the Hawrān region maintained a stylistic corbelling culture. Nevertheless, despite many churches in Umm el-Jimal, no single example is sure that the roofing style could have taken such a 'multi-layered' flat configuration. The hypothesis is still isolated and only loosely connected to the broader historical context of the Hawrān region. Alternatively, the first hypothesis of *stylistic-based reconstruction* and the third hypothesis of *engineering-based reconstruction* prove their relevance in this study because of pioneering examples in the Hawrān region. The composite view is of particular curiosity. On the one hand, it may appear unconvincing because combining flat and arcuated arrangements in the same place is unusual. On the other hand, it suggests that the forms of church architecture might have been automatically chosen for their stylistic architecture and because they are structurally the most appropriate, especially in regions endangered by natural hazards such as earthquakes and landslides. The *hybrid 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 lateral out-of-plane loading and the in-plane load, leading to recurrent collapses and damage to the structure.

Conclusion

The Western 'classical template' of church design is scarcely challenged in both theory and practice. On the other hand, scholars generally agree that church architecture developed along the lines of the 'classical prototype' of spatial arrangement and architectural character in the west. This research intends to propose an alternative engineering-based reconstruction technique for archaeological sites with distinctive building materials and structural systems, such as the Hawrān region's basaltic corbelled church buildings. The epistemic engineering-based reconstruction is based on a unique interpretation of the apse structural system. It highlights the importance of contextualized 'historical research' in understanding church engineering as a scientific discipline and how scientific knowledge is perceived and disseminated.

The engineering-based model grounds reconstruction in a scientific framework that extends beyond geometric morphology and architectural styles. It reconstructs the building's manufacturing process by considering structural systems, construction processes, and sustainability measures. However, attempts at reconstruction do not mean that the reconstruction is identical to the historical church in its original state. In reconstructing a lost heritage, the literature highlights the challenges of 'completeness,' 'accuracy,' validity, trustworthiness, and utility ([4: 54, 59]). It does, though, provide a valid and scientific interpretation of the building structure, demonstrating the difficulty of documenting the reconstruction process and limiting misunderstandings of the translation of earlier 2D and 3D drawings produced by studies based on limited archaeological findings and without reference to the broader historical context.

The study borrows from the field of digital and virtual archaeology and utilizes three-dimensional modeling to visualize reconstructive hypotheses of 'uncertain' heritage. The idea of the diverse roofing structures remains dubious. It is well recognized that historic reconstruction requires historical and architectural investigations, but more importantly, quantitative analysis that permits material and structural analysis, monitoring, and structural analysis [1, 7]. Future research attempts for ecclesia architecture in the Hawrān region could refer to the three hypothetical reconstruction models advanced in this study to conduct quantitative analysis based on mathematical simulation (such as the Finite Element

Method- FEM) or experimental analysis (laboratory tests). In collaboration with a team of academic experts in civil engineering for historic buildings, the first author is currently conducting research that tests the load-performance of the three hypotheses that have been addressed in this study. A similar examination should be discretely considered for each case to ensure the least invasive and most compatible conservation interventions.

Abbreviations

ICOMOS: International Council on Monuments and Sites; 2D, 3D: Two-dimensional and three-dimensional architectural drawings.; CE: Common era; BCE: Before common era; FEM: Finite element method; *ill*: Illustration.

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Author contributions

Rama and Shaher discussed the content and structure of the manuscript and the presented hypotheses. Rama (the primary author) wrote the main manuscript text and prepared the figures after discussing them with the co-author (Shaher Rababeh). Both authors read and approved the final manuscript.

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Declarations

Competing interests

The research does not involve potential competing interests.

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