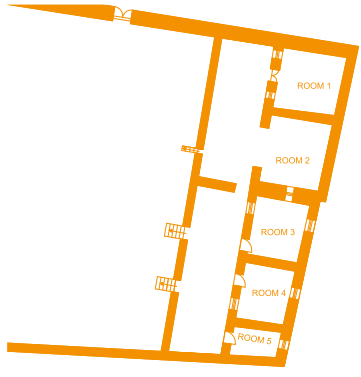
Characterization of architectural binders and spatial configuration of the Alrousan courtyard house in Ottoman Umm Qais, Jordan



Abstract: The architectural heritage of rural northern Jordan during the Ottoman period reflects a complex interplay of environment, technology, and sociocultural structure, which is evident in the traditional courtyard houses of Umm Qais. This study investigates the material characterization of the Alrousan courtyard house using petrography and X-ray diffraction, as well as spatial configuration through space syntax analysis using depthmapX software, in order to explore historical construction practices and social organization. The study is based on ten mortar and plaster samples collected from different parts of the house. The results reveal the widespread use of basalt and micritic limestone, suggesting continuity in material selection and preparation techniques from the Byzantine to the Ottoman periods, although there may have been a decline in craftsmanship during the occupation period. The courtyard functioned as a social hub, while the rooms were more isolated spaces reflecting privacy, gender segregation, and family structure. This interdisciplinary approach provides valuable insights into the technological and cultural legacy of domestic architecture in historical Jordan. The Alrousan house represents a model of the interaction among local resources, environmental conditions, and social traditions that shaped architectural design and construction techniques.

Keywords: courtyard houses (*Ḥawsh*), Gadara (Umm Qais), Ottoman period, petrography, XRD, VGA analysis

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INTRODUCTION

Mortars and plasters, as architectural binders, have been used for several purposes in traditional architecture, including pointing, finishing, coating, and serving as hydraulic binders for terraces and water systems. However, environmental conditions and aging compromise their physical integrity, necessitating restoration plans that adhere to the principles of material compatibility and authenticity (Hao et al. 2024). Such plans usually begin with the characterization of these materials, which identifies their composition as well as their physical, chemical, and mechanical properties, together with the quality of the aggregates (Loke, Pallav, and Haldenwang 2020). In many cases, conservation scientists have been able to evaluate the craftsmanship of the original masons, understand how materials adapted to local environmental conditions, and compare mortars and plasters from different sites (Middendorf et al. 2005). Lime-based mortars and plasters were developed and used during the Neolithic in Jordan, Palestine, and Turkey, about 12000 BC, and later through the Chalcolithic period, like the polychrome wall paintings discovered at Teleilat Ghassul (Garfinkel 1987; W.D. Kingery et al. 1988; von Landsberg 1992; Griffin, Grissom, and Rollefson 1998; Elert et al. 2002; Clarke 2012; Drabsch and Bourke 2019; Friesem et al. 2019). They became widely used during the classical period and remained common until the 18th century, when hydraulic binders largely replaced lime because they harden more rapidly and possess superior mechanical properties (Özer and Acun Özgünler 2023). Although plasters and mortars have been extensively studied at archaeological sites in Jordan (Dunn and Rapp 2004; Alawneh et al. 2011; Al-Bashaireh and Hodgins 2012; Bonazza et al. 2013; Yaseen et al. 2013; Al-Naddaf and El-Khouri 2014; Al-Bashaireh 2016; 2019; 2024; Al-Shereideh et al. 2018; Tenconi et al. 2018; Sekhaneh et al. 2020; Al-Saad and Bataineh 2021; Daugbjerg et al. 2022a; 2022b; Seiseh et al. 2023; Al-Tell et al. 2025), historical binders from Ottoman domestic architecture remain comparatively understudied.

The present study aims to characterize chemically and analytically the plasters and mortars of the Alrousan Ottoman courtyard house at Umm Qais in northern Jordan in order to better understand its building technology, raw materials,



Fig. 1. Map of Jordan showing the location of Umm Qais (Processing Waleed Abu Alhayjaa)

and construction history [*Fig. 1*]. In addition, the study employs space syntax theory to examine the social, political, and economic functions of courtyard houses, based on the assumption that the courtyard is not merely an external extension of the dwelling but a spatial manifestation of social organization (Lévi-Strauss 1967). By quantifying the relationships among the various spatial elements within the house, it is possible to infer social hierarchies, gender dynamics, and economic activities (Hillier and Hanson 1984; Al-Hagla 2010; Alhusban and Al-Shorman 2011). The introverted design of courtyard houses has been interpreted both as a cultural symbol (Rapoport 1969) and as an economically efficient urban form that reduces external wall exposure and optimizes passive cooling (Fathy 1986). Furthermore, their layout often reinforced political structures, while segregated spaces reflected class or familial authority (Hakim 2007). Accordingly, integrating material-science analysis with spatial analysis provides a more comprehensive understanding of Ottoman domestic architecture by linking construction techniques to broader socio-environmental contexts.

HISTORICAL CONTEXT

THE CITY OF UMM QAIS

The city of Umm Qais (Gr. Γάδαρα) is one of the Decapolis cities in northwestern Jordan, overlooking the Yarmouk River and Lake Tiberias at an elevation of approximately 378 m above sea level. Umm Qais enjoys a Mediterranean climate, with average annual precipitation of around 450 mm and a mean annual temperature of approximately 30°C. The archaeological remains are situated on a narrow ridge extending for about 1.6 km and descending steeply toward the Yarmouk River (Kennedy and Bewley 2004). Geologically, Umm Qais lies on a saddle between two distinct formations: the Eocene Umm er-Rijam Chert Limestone to the east and a Pliocene–Pleistocene basalt plateau to the west (Moh'd 2000). This setting has produced considerable geomorphological variation, with the basaltic areas forming relatively flat plains covered by deep, homogeneous soils, while the limestone areas are heavily dissected and display variable soil thickness (National Soil Map and Land Use Project 1993). The modern residential area of Umm Qais is located atop a limestone hill (Bührig 2009). The fertile landscape surrounding Umm Qais, together with its proximity to perennial water sources from the Yarmouk River and Lake Tiberias, attracted Greek, Roman, Byzantine, and Islamic civilizations, all of which left remarkable monuments and archaeological remains that testify to the region's cultural development and human achievements. As a result, Umm Qais provides a representative model of the physical and cultural characteristics shared by the other Decapolis cities in Jordan (Keilholz 2014: 27).

During the second half of the 1st millennium BC, present-day Jordan came under the rule of Alexander the Great. After his death in 323 BC, his empire was divided among his successors. Gadara subsequently became part of the terri-

tory of the Ptolemaic Kingdom, whose frontier with the Seleucid Empire followed the Yarmouk River. The earliest historical references to Gadara describe it as a military stronghold. In 218 BC, the Seleucid King Antiochus III captured the city, incorporating it into the Seleucid Kingdom. In 63 BC, the Roman General Gnaeus Pompeius brought the Levant under Roman control, and Gadara became part of the Roman sphere. Although the siege of 63 BC damaged the city, it was subsequently rebuilt along with other urban centers in the region (Al Shiyab, Alawneh, and Al-Sababha 2021). Gadara later became one of the Decapolis cities, sharing political, cultural, and economic interests with the other members while retaining a degree of autonomy. The city thrived economically and culturally during the late 1st and 2nd centuries AD (Seetzen 1859; Peake 1958; Browning 1982; Segal 1988). This prosperity coincided with intense urban development and an increasing demand for water, despite the presence of 11 springs in the vicinity: ʻAyn al Fakhet, ʻAyn Khanzereh, ʻAyn Ma quq, ʻAyn Shyhann, ʻAyn al Tabbaq, ʻAyn Qart, ʻAyn al ʻAssal, ʻAyn Turab, ʻAyn al Hartheen, ʻAyn al Shaykh, and ʻAyn Khraj (Schumacher 1890; Glueck 1951; Weber 1991). To cope with water shortages, the inhabitants constructed cisterns and water tunnels that conveyed water from considerable distances, in a manner comparable to the system developed at Abila of the Decapolis during the Hellenistic and Roman periods (Al-Shorman 2022). The increasing population eventually forced the city to expand westward, particularly during the Late Roman and Byzantine periods (Maxwell 1990).

Occupation continued during the Umayyad period without major changes, although some buildings fell into disuse, deteriorated, or were assigned new functions. Archaeological excavations at the basilica indicated that it had ceased to be used, and by the mid-8th century the structure was probably destroyed by the earthquake of AD 746/747 (Wagner-Lux and Vriezen 1980; Lucke et al. 2012). The Great Bathhouse, located on the southern side of the Decumanus Maximus, was converted into residential units during the same period. In addition, the nymphaeum was destroyed either near the end of the Byzantine period or in the early Umayyad period. According to Wagner-Lux and Vriezen (1980), the city was abandoned during the 9th century AD.

Archaeological evidence suggests that during the Mamluk period settlement at the site of ancient Gadara was concentrated mainly in its western sector. The large bath complex along the Decumanus Maximus was reused as a residence, and the round building was adapted for use as a reservoir. Approximately 40–50 m north of the round building, the remains of what were likely residential structures have also been attributed to the Mamluk period. Additional evidence of Mamluk occupation has been identified at nearby sites, including Khirbet Umm al-Nimal (about 3 km south of Gadara), Khirbet al-Tabaq (4.7 km southwest), and Khirbet al-Buwayr (4.7 km southeast) (Holm-Nielsen, Nielsen, and Andersen 1986). Following the Ottoman annexation of the region in 1517, the site of ancient Gadara experienced continued and gradual reoccupation, which intensified during the late Ottoman period.

Umm Qais was recorded in Ottoman tax registers of 1596 as a village, providing important evidence for its economic activities (Hütteroth and Abdulfattah 1977). Seasonal occupation became a significant feature of the settlement in the modern period. European explorers of the 19th century, including Ulrich Seetzen, Charles Leonard Irby, James Mangles, and James Silk Buckingham, described Umm Qais as a small village whose inhabitants often lived in ancient tombs. Seetzen (1810) recorded a population of six or seven families in 1810. Fifteen years later, Buckingham (1821) estimated the population at approximately two hundred inhabitants, although during an earlier visit he described the site as uninhabited. Such fluctuations in population may have resulted from drought, heavy taxation, and militarization (Shami 1987). Ottoman land registration in the mid-19th century facilitated the formation of the permanent village of Umm Qais, now known as Hara Foqa. Many families benefitted from the new landownership policies and constructed courtyard houses (Mershen and Knauf 1988). During the 20th century, these family housing complexes expanded over successive generations. After the 1967 war, archaeological excavations of the Graeco-Roman ruins began, and the Jordanian government later purchased approximately 450 dunums of land and relocated the villagers to a newer settlement east of

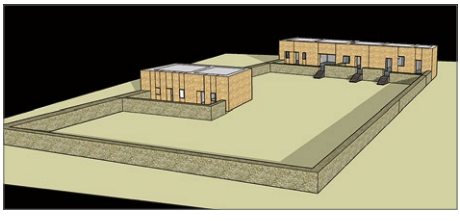

Fig. 2. 3D model of the Alrousan courtyard house (Abdulla Al-Shorman)

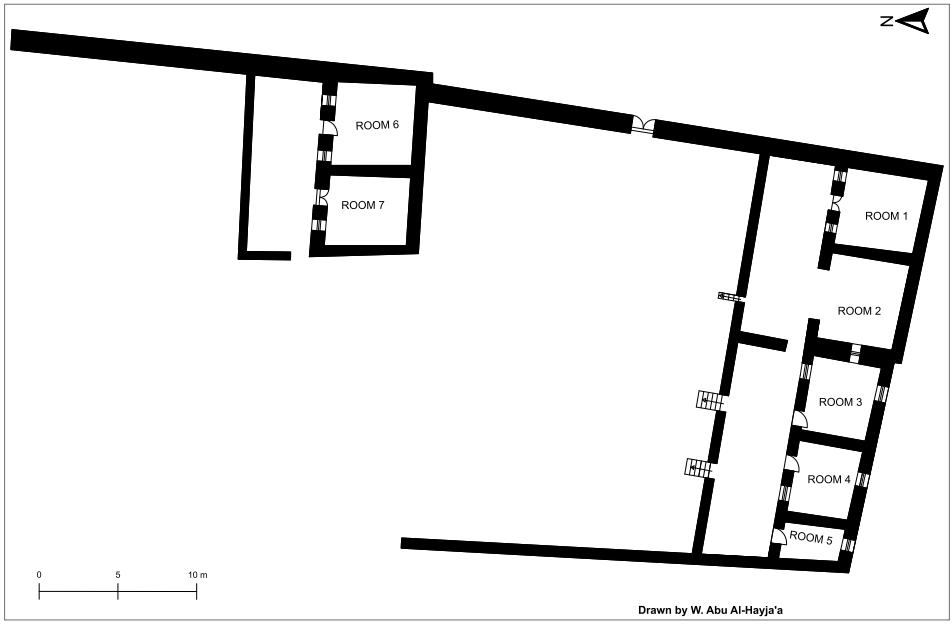

Fig. 3. Plan of the Alrousan courtyard house (Drawing Waleed Abu Alhayjaa)

the ruins (Brand 2000). The Ottoman village subsequently became a heritage site in its own right [see *Fig. 1*].

ARCHITECTURAL DESCRIPTION OF THE ALROUSAN COURTYARD HOUSE

The studied courtyard house is located in Umm Qais in northern Jordan, within the boundaries of the former Decapolis city of Gadara. Although occupation of the site is believed to have begun during the Paleolithic period, prosperity and cultural development reached their peak during the classical period (332 BC–AD 640) before declining in the aftermath of the AD 746/747 earthquake (Wagner-Lux and Vriezen 1980). The landscape is rugged, and the site lies at an elevation of approximately 267 m above sea level. Umm Qais enjoys a Mediterranean climate, with average summer temperatures of around 30°C and average winter rainfall of about 250 mm. At the time when the house was established, annual rainfall was probably above the drought threshold of 217 mm (Alhusban and Al-Shorman 2011).

Architectural documentation of the courtyard house was based on field recording, measured sketching, and on-site verification, since no previous formal architectural survey of the structure has been identified in published records. The courtyard house (*Ħawsh*) belonged to a tribal leader (*sheikh*) named Salih Alrousan [*Figs 2, 3*]. The house consists of two residential units containing seven rooms in total, together with a porch, a courtyard, and a stable, all enclosed by a stone wall. A window between Rooms 2 and 3 suggests that the building was expanded during later phases of occupation. The residential units were constructed during the 19th century reusing dressed stones taken from nearby archaeological ruins. The walls are double-layered, with the space between the two faces filled with small boulders and soil. The roof was composed of three layers: wooden logs, reeds and dry vegetation, and a final layer of mud mixed with hay. The doors and windows were made of wood, while the windows were additionally protected by iron bars for security purposes. The roof was replastered annually before winter, and the rooms were plastered with mortar and coated with lime wash [*Figs 2, 3*].

LITERATURE REVIEW

The detailed technological history of lime plasters is discussed in the Introduction; this section focuses only on studies directly relevant to analytical characterization and architectural interpretation.

The characterization of lime plaster and mortar can reveal past technological knowledge, construction sequences, and regional craftsmanship (Middendorf et al. 2005; Arizzi and Cultrone 2021). The literature identifies several analytical techniques used for this purpose, including petrography, X-ray diffraction, Fourier transform infrared spectroscopy, scanning electron microscopy, and chemical assays (Singh, Waghmare, and Kumar 2014; Prieto-Vicioso et al. 2022). These methods identify the aggregates and binders used, which in turn provide evidence of resource availability and

technological choices (Pivák et al. 2024). Studies in Jordan have shown that local aggregates such as micritic limestone and volcanic basalt, together with organic tempering agents such as chaff, were commonly employed (Sauer 1986; Middendorf et al. 2005; Al-Naddaf and El-Khouri 2014; Al-Shereideh et al. 2018).

Historical architecture in the Levant demonstrates both continuity and change in material practices over time. Although lime mortars remained dominant, some periods, particularly the post-Byzantine and Ottoman eras, witnessed the introduction of new materials such as Portland cement, either as a result of technological transfer or economic accessibility (Alhusban and Al-Shorman 2011). The occurrence of mixed materials (mud, lime, and cement) in Ottoman-period houses such as the Alrousan courtyard house reflects a transitional phase in which older methods coexisted with newer innovations. The quality of mortars may have declined during later historical periods because of reduced craftsmanship or economic constraints (Arizzi and Cultrone 2021). Mud plasters, although cheaper and easier to apply, lacked the durability of lime-based mortars, and their friability often indicates either limited technological expertise or shortages of suitable materials (Maheri et al. 2011).

The courtyard-house typology reflects social organization, environmental adaptation, and cultural symbolism in Middle Eastern architecture (Huang, Chiou, and Li 2019; Zhang 2020; Gupta and Joshi 2021). Such houses have been interpreted as spatial expressions of kinship, privacy, gender roles, and authority (Lévi-Strauss 1967; Hillier and Hanson 1984). In Ottoman Jordan, and particularly in Umm Qais, the reuse of ancient building materials in courtyard houses may symbolize continuity and resourcefulness (Selim et al. 2021). Historical domestic architecture in northern Jordan typically consisted of large, multigenerational homes organized around interior courtyards that functioned both as climatic moderators and as social centers (Alhusban and Al-Shorman 2011). The use of local materials, such as basalt and limestone, together with annual maintenance practices including replastering, exemplifies sustainable building traditions adapted to the Mediterranean climate (Mazzetto 2025).

The incorporation of space syntax theory into architectural studies has enabled scholars to quantify the relationship between spatial layout and social behavior (Hillier and Hanson 1984). Previous studies have analyzed how architectural space guides movement, reinforces privacy, and reflects social hierarchies through the use of visibility graph analysis, reference numbers, mean depth, and agent simulation (Koutsolampros et al. 2019). In the Levantine context, space syntax has been employed to assess how gender, hierarchy, and hospitality are embedded in the physical structure of houses (Al-Hussayen 1999; Bianca 2000). The differentiation between public spaces (e.g. courtyards) and private spaces (e.g. sleeping rooms) reflects broader socio-religious values and changing household compositions over time (Rapoport 1980; Parker 2015).

Umm Qais represents a layered historical site with occupational continuity from the Paleolithic period to modern times. Its limestone and basalt formations have significantly influenced building

materials and construction techniques throughout its history (Moh'd 2000; Keilholz 2014). Archaeological surveys have documented both the reuse of classical-era stones in Ottoman buildings and the adaptation of Graeco-Roman planning concepts into vernacular architectural forms (Bührig 2009; Hoffmann and Bührig 2013). The late Ottoman village of Umm Qais demonstrates a hybrid architectural legacy in which economic limitations, changing land policies, and tourism-related displacement all played important roles in shaping the built environment (Mershen and Knauf 1988). Within this context, the Alrousan courtyard house offers a valuable case study for exploring material continuity, social organization, and environmental adaptation over time.

MATERIALS AND METHODS

To obtain a representative analysis, ten plaster and mortar samples (S.1–S.10) were collected from different parts of the courtyard house [*Table 1*]. Five samples date to the Ottoman period (S.2, S.3, S.7, S.8, S.9), four to the early 20th century (S.1, S.4, S.5, S.6), and one (S.10) to the Byzantine period. This sample was included to investigate continuity or change in lime plaster and mortar technology. Sampling was conducted on the basis of visual assessment of the state of preservation, spatial distribution, and the functional diversity of the rooms. Room 5 was not sampled because it was closed and is currently used as storage by the local Department of Antiquities of Umm Qais. In addition, Room 8 was not sampled because sample S.8 was considered representative of the plaster applications shared by Rooms 6 and 7, based on macroscopic inspection of texture, layering, and color [*Fig. 4*].

Table 1. Sample type, date, and location

Sample No.	Type	Date	Location
1	Portland cement	1950s	Southern exterior wall
2	Lime mortar	Ottoman	Southern exterior wall
3	Mud painted plaster	Ottoman	Room 3
4	Portland cement	20th century	Room 3
5	Portland cement	20th century	Room 4
6	Portland cement	20th century	Room 4
7	Basaltic plaster	Ottoman	Room 2
8	Basaltic floor pavement	Ottoman	Room 7
9	Mud plaster and mortar	Ottoman	Room 1
10	Byzantine plaster	Byzantine	Exterior wall of the fence

Three slices were prepared from each sample using a Buehler Isomet™ low-speed precision diamond saw, which minimizes heat generation and mechanical deformation during cutting. One slice from each sample was prepared as a 30 µm-thick section following standard petrographic procedures. These sections were examined under a Leica refracted polarized-light microscope to determine

grain morphology and identify non-plastic inclusions. The second slice was ground into a fine powder using an agate mortar and pestle to ensure homogeneity and was then analyzed with a Shimadzu XRD-600 diffractometer using Cu-Kα radiation (λ=1.5406 Å), operating at 40 kV and 30 mA. Scans were performed over a 2θ range of 5°–70°, with a step size of 0.02° and a scan speed of 2°/min. This technique was used to characterize the mineralogical composition and major chemical constituents of the samples. Three grams of material from the third slice were treated with 3% hydrochloric acid (HCl) to remove dissolved carbonates and soluble salts, following the procedure outlined by Middendorf et al. (2005). The remaining residue was dry-sieved through a standard set of stainless-steel mesh sieves with apertures of 0.630 mm, 0.500 mm, 0.250 mm, and 0.125 mm. The aggregate-to-binder ratio was then recorded for each sample in order to assess the recipes and production techniques of the original mortars and plasters.

Space syntax theory was employed to investigate the socio-spatial logic and dynamics of the house (Hillier and Hanson 1984). Accordingly, the spatial configuration of the courtyard house was analyzed using depthmapX software following Turner (2001). The analysis included visibility graph analysis (VGA), reference number (RN), mean depth (MD), connectivity (CN), and agent simulation (AS). VGA was used to map visible connections among rooms and the courtyard. RN quantified how easily each space connected to the overall layout, while MD measured the relative depth of spaces within the spatial system. Together, VGA, RN, and MD were used to identify spaces that controlled movement and those that were relatively isolated. CN and AS were employed to identify local visibility hotspots and to model likely movement patterns within the house.

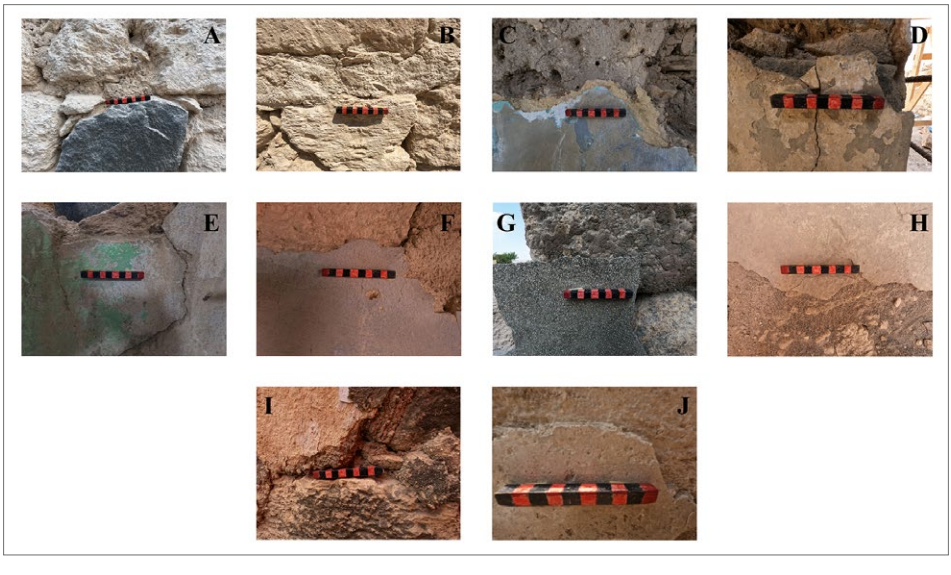

Fig. 4. Locations of the collected samples (Photos Hussein Al-Sababha)

RESULTS. MATERIAL ANALYSIS

The XRD results show that calcite and quartz are the most abundant mineral phases in all samples, consistent with lime-based mortars and the incorporation of quartz-rich aggregates. Many samples also contain additional minerals, including albite (S.2 and S.3) and plagioclase (S.4, S.7, and S.8), while chert is present in S.7, S.8, and notably in the Byzantine sample S.10. These variations may indicate the use of different geological sources for aggregates or chronological differences in construction techniques.

Petrographic analysis enabled a more detailed comparison of microtextures and inclusions among the samples. One group of samples, characterized by a muddy, homogeneous matrix, displayed similar ingredients and preparation techniques and resembled modern Portland mortar and plaster in consistency. This homogeneity suggests the use of comparable raw materials and probably a consistent preparation method, largely based on lime slaking and fine sieving. The other group, represented by samples from Rooms 2 and 7, exhibited a significantly different aggregate profile. The plaster sample from Room 2 (S.7), for example, displayed a relatively coarse texture and darker appearance, correlating with its high proportion of coarse aggregates and the presence of basalt clasts, although basalt itself accounted for only 5% of the total composition. The higher basalt content may reflect either a functional requirement for increased strength or the availability of local materials, supporting the interpretation of context-specific variation in mortar recipes within the same construction phase.

Petrographic examination further showed that grains in most Ottoman samples are sub-rounded, indicating some degree of mechanical weathering prior to mixing. In contrast, angular grains are more pronounced in S.4, S.9, and S.10, possibly indicating freshly crushed aggregates or differences in preparation techniques. Grain size ranges from fine to coarse across all samples, with considerable variability both between and within individual samples, suggesting a non-standardized process of sieving or aggregate selection. On the basis of their mineralogical characteristics, the samples can be divided into three groups. The first group (S.4, S.7, and S.8) consists of plasters composed of calcite, quartz, and plagioclase and appears to represent a later phase of occupation in the courtyard house. The second group (S.2 and S.3) comprises lime mortar and plaster containing calcite, quartz, and albite, representing an earlier phase of occupation. The third group (S.1, S.6, S.9, and S.10) consists of exterior lime plasters composed primarily of calcite and quartz and appears to represent the earliest phase of occupation, beginning in the Byzantine period. Accordingly, the results suggest that Rooms 3 and 4, and possibly Room 5, were among the earliest areas to be constructed and occupied, followed by the addition of Room 1 using the earlier fence wall, and subsequently Rooms 2, 7, and 8. This interpretation is supported by similarities in non-plastic inclusions within each group and by differences among the three groups, which may reflect either functional adaptations

or temporal variation despite an overall continuity in mortar preparation techniques.

The distinctive combination of calcite, basalt, and chert fragments, together with the greater angularity of grains in the Byzantine sample (S.10), may indicate a gradual change in mortar recipes and material selection during successive phases of occupation. Taken together, the mineralogical and petrographic data point to a flexible yet systematic approach to mortar production. The builders appear to have relied primarily on locally available materials while adapting mortar recipes to architectural function and, possibly, to later building expansions [*Fig. 5*, *Table 2*].

Table 2. Non-plastic inclusions, grain size, shape, composition, and mineral phases of samples identified by petrography and XRD

Sample No.	Non-plastic inclusions	Grain size	Grain shape	Composition %	Mineral phases	Room
S.1	Micritic limestone, one basalt clast, quartz	Fine–medium	Sub-rounded	5% basalt	Calcite, quartz	1
S.2	Basalt, micritic limestone, primary calcite	Fine–medium	Sub-rounded	20% limestone, 10% basalt	Calcite, quartz, albite	1
S.3	Micritic limestone, a few basalts, chaff	Fine–medium	Sub-rounded	30% calcite, 20% chaff, 10% basalt	Calcite, quartz, albite	3
S.4	Cementite, basalt, micritic limestone, quartz	Medium–large	Angular	30% calcite, 15% basalt, 5% quartz	Calcite, quartz, plagioclase	3
S.5	Calcite, basalt, quartz	Fine–large	Sub-rounded	30% calcite, 15% quartz, 5% basalt	Calcite, quartz	4
S.6	Calcite, basalt, quartz	Fine–large	Sub-rounded	30% calcite, 15% quartz, 5% basalt	Calcite, quartz	4
S.7	Chert, basalt, calcite, quartz	Fine–large	Sub-rounded	20% calcite, 20% quartz, 5% basalt, 2% chert	Calcite, quartz, plagioclase	Wall of Room 2
S.8	Calcite, chert, basalt	Fine	Sub-rounded	30% calcite, 15% basalt, 5% chert	Calcite, quartz, plagioclase	7
S.9	Calcite, chaff, basalt, quartz	Medium–large	Angular	30% calcite, 2 0% chaff, 5% basalt, 5% quartz	Calcite, quartz	1
S.10	Calcite, basalt, chert	Fine–large	Sub-rounded-angular	35% lime, 5% basalt, 2% chert	Calcite, quartz	Western fence

The mortar and plaster samples (S.1–S.10) from the Alrousan courtyard house were quantitatively analyzed to determine granulometric distribution, binder and aggregate content, and binder-to-aggregate ratios using dry sieving, acid digestion with 3% HCl to estimate calcite-based binder content, and mass-balance calculations. The results show significant variation in aggregate composition and binder content across the samples [*Table 3*]. The weight of the fine matrix (assumed to represent binder and fines) was calculated by subtracting the weight of the sieved aggregates from the original 3 g sample. The binder-to-aggregate ratio is 1:2 for samples S.1, S.3, S.5, and S.9; 1:4 for sample S.2; and 1:3 for samples S.4, S.6, S.7, S.8, and S.10. The relatively high binder content in samples such as S.1

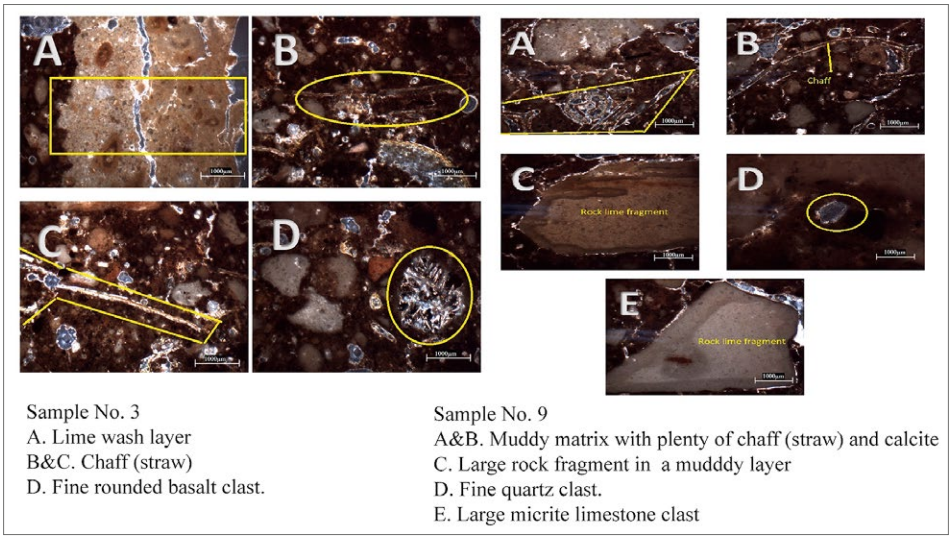

Fig. 5. Photomicrographs showing the texture and non-plastic inclusions of selected samples (Hussein Al-Sababha)

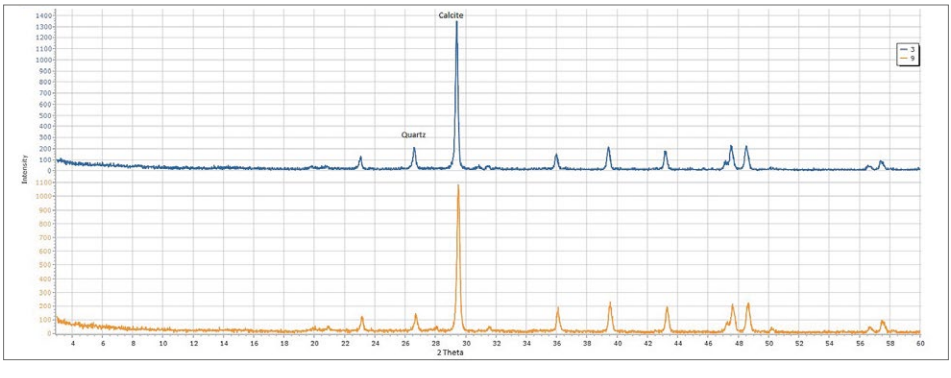

Fig. 6. X-ray diffractograms of samples S.3 and S.9 showing similar mineralogical compositions (Hussein Al-Sababha)

and S.3 is associated with their muddy texture and fine grain size. This suggests a homogeneous lime-rich mortar that visually resembles modern Portland-style mortar in consistency, although not in composition. These samples may reflect a shared preparation technique involving careful lime slaking and fine sieving. The coarsest fractions (≥1 mm and 0.500 mm) dominate the aggregate profile in samples such as S.7 and S.4, which is consistent with the abundance of basalt clasts. The presence of coarse aggregates (about 60% in S.7) strongly indicates a deliberate use of basalt-rich material as aggregate. By contrast, samples such as S.1, S.3, and S.5 exhibit a more even distribution of grain sizes across the fine-to-medium fractions, supporting the hypothesis of a different functional or chronological context.

Sample S.1, collected from the southern wall of Room 1, has a binder-to-aggregate ratio of 1:2 and a relatively high calcite content (0.871 g), indicating a lime-rich matrix. Its sieving profile shows moderate particle-size gradation, suggesting a refined mixing technique. In contrast, sample S.7, taken from the wall between Rooms 2 and 3, has a lower binder content (0.60 g) and a higher

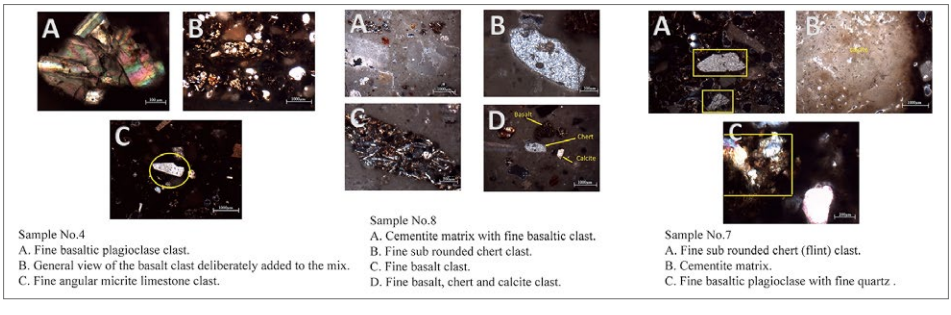

Fig. 7. Photomicrographs showing the texture and non-plastic inclusions of selected samples (Hussein Al-Sababha)

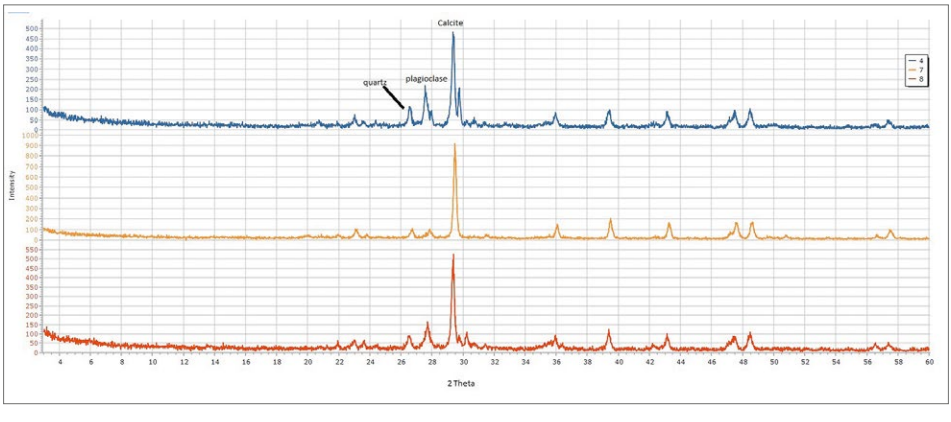

Fig. 8. X-ray diffractograms of samples S.4, S.7, and S.8 showing similar mineralogical compositions (Hussein Al-Sababha)

proportion of coarse basaltic inclusions, indicating that the mortar was prepared to meet different structural requirements. The presence of plagioclase in S.7 and its absence in S.1, together with differences in aggregate coarseness and binder proportion, point to functional variation and may support the hypothesis that Room 1, and possibly Room 2, belong to a later occupation phase. It is plausible that Room 2 was added first, as it contains a window in the wall separating it

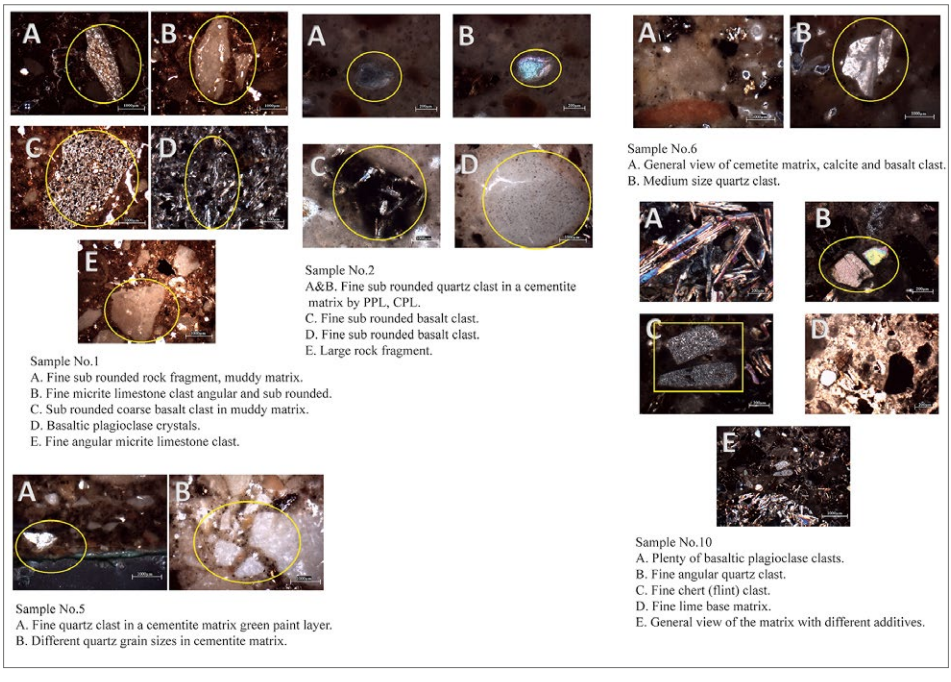

Fig. 9. Photomicrographs showing the texture and non-plastic inclusions of selected samples (Hussein Al-Sababha)

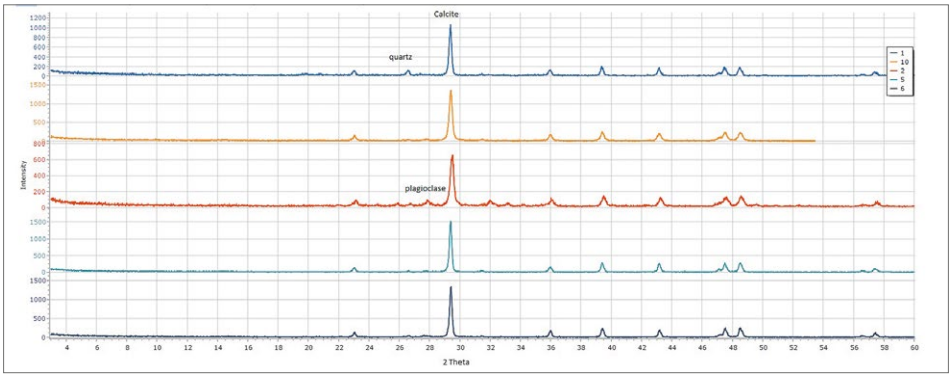

Fig. 10. X-ray diffractograms of samples S.4, S.7, and S.8 showing similar mineralogical compositions (Hussein Al-Sababha)

from Room 1. Unlike the other rooms, Rooms 1 and 2 lack windows on the southern wall because this wall formed part of the pre-existing perimeter enclosure and had already been constructed to a considerable height. The Byzantine sample (S.10) also displays a 1:3 binder-to-aggregate ratio, and its sieving results indicate a moderately coarse texture. This supports a chronological distinction in mortar technology, even though lime remained the dominant binder component throughout all phases of occupation.

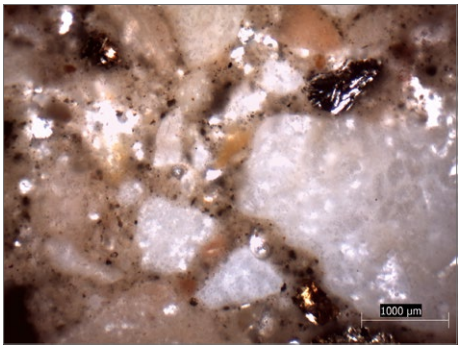

Fig. 11. Photomicrographs showing lime lumps with a bimodal size distribution (Hussein Al-Sababha)

The quantitative analysis of binder and aggregate proportions provides strong evidence for flexible yet deliberate construction techniques guided by local resource availability, functional requirements, and possibly chronological changes in building practice. This is evident in the differences, even if relatively small, between the Byzantine sample S.10 and the Ottoman-period samples. Such compositional variations may also correspond to broader architectural changes, including room additions and structural modifications [*Figs 6–11*].

Table 3. Sieving analysis of the samples

Sample No.	Weight (g)	Sieving profile according to aperture size						Total wt. after sieving (g)	Calcite dissolved in 3% HCl (g)	Binder (g)	Aggregate (g)	Binder-to-aggregate ratio
		1 mm	0.500 mm	0.250 mm	0.125 mm	0.630 mm	0 mm					
S.1	3	1.169	0.47	0.28	0.16	0.05	0	2.129	0.871	1.081	1.919	1:2
S.2	3	1.59	0.54	0.22	0.09	0.04	0	2.48	0.52	0.65	2.35	1:4
S.3	3	1.25	0.39	0.24	0.15	0.08	0.04	2.15	0.85	1.08	1.88	1:2
S.4	3	1.28	0.66	0.33	0.1	0.04	0	2.41	0.59	0.73	2.27	1:3
S.5	3	1.18	0.56	0.31	0.19	0.09	0	2.33	0.67	0.95	2.05	1:2
S.6	3	1.16	0.66	0.31	0.19	0.05	0.02	2.39	0.61	0.85	2.13	1:3
S.7	3	1.34	0.68	0.23	0.11	0.04	0	2.4	0.6	0.75	2.25	1:3
S.8	3	0.77	0.89	0.55	0.15	0.04	0	2.4	0.6	0.79	2.21	1:3
S.9	3	0.97	0.54	0.32	0.2	0.11	0.05	2.19	0.81	1.12	1.83	1:2
S.10	3	0.95	0.84	0.36	0.2	0.08	0	2.43	0.57	0.85	2.15	1:3

In all samples, lime lumps ranging in size from 40–1000 µm were observed. Many of these lumps exhibit dissolution features that increase secondary porosity in the mortars and plasters. Their presence should therefore be examined carefully in order to understand the reasons for their formation. The properties of slaked lime (calcium hydroxide) or the water-to-lime ratio may be responsible for this phenome-

non. Incomplete slaking of calcium hydroxide can produce lime with low plasticity; when combined with a low water-to-lime ratio, this reduces the workability of the lime-aggregate mixture. Under such conditions, nodules of slaked lime may form and subsequently carbonate to produce calcium carbonate nodules (lime lumps). Because lime lumps have essentially the same chemical composition as the binder, comparing the lime lumps with the surrounding binder within the same sample can provide useful information about the degree of hydraulicity of the binder.

RESULTS. SPACE SYNTAX ANALYSIS

Results of the VGA analysis reveal a clear spatial hierarchy and intentional zoning across the different construction phases of the house [*Table 4*; *Figs 12–15*]. It is possible that Rooms 1 and 2 were added during a later phase of occupation, probably in response to an increase in the size of the extended family. This interpretation is supported by the petrographic and XRD analyses. The entrance-courtyard zone exhibits relatively high values compared to other VGA metrics, including reference number, mean depth, connectivity, and agent density. As a visually shallow and spatially accessible zone, it appears to have functioned as a central area for social, political, and economic activities within the household (Alhusban and Al-

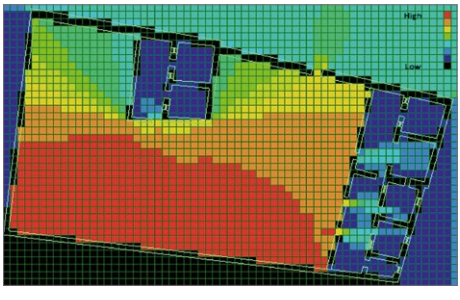

Fig. 12. Visibility graph analysis (VGA) of the courtyard house (Abdulla Al-Shorman)

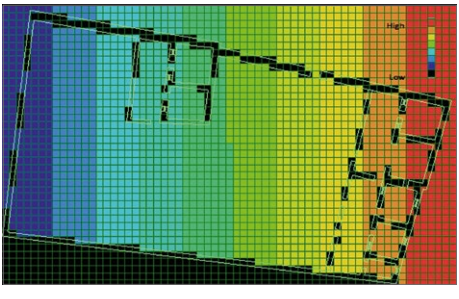

Fig. 13. Reference number (RN) analysis (Abdulla Al-Shorman)

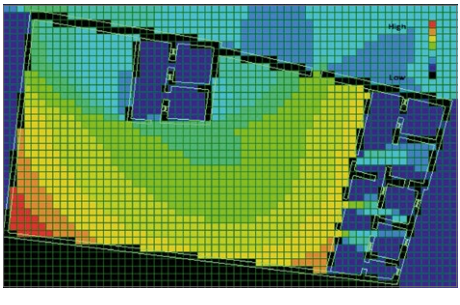

Fig. 14. Mean depth (MD) analysis (Abdulla Al-Shorman)

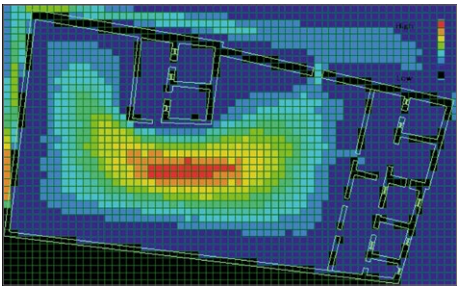

Fig. 15. Agent simulation (AS) analysis (Abdulla Al-Shorman)

Shorman 2011). Although the courtyard has a relatively high mean depth (visually distant from rooms), it remains functionally significant because of its high connectivity, indicating strong and direct visual links with adjacent spaces. In addition, the elevated AS suggests that this area experienced substantial movement and activity, making it the primary social hub of the house.

By contrast, the VGA metrics for the rooms display generally lower values, suggesting that they were visually deeper and more socially detached from the rest of the house. Their low connectivity values indicate limited direct visual access and reinforce their separation from the main circulation routes associated with the courtyard. In addition, the low agent density suggests that these spaces were less frequently accessed in simulated movement patterns, supporting their interpretation as private or restricted areas. Taken together, these findings emphasize the deliberate spatial organization of the house, in which visibility, accessibility, and movement were carefully managed to reflect social norms and functional requirements typical of traditional domestic architecture [see *Figs 12–15*].

Table 4. Results of visibility graph analysis

Metric	Entrance to courtyard	Private rooms
Reference number	High (visually shallow, closely connected to other spaces)	Low (visually deep)
Mean depth	Relatively high	Relatively low
Connectivity	High (visually open)	Low (segregated)
Agent density	High (intense movement)	Low (limited movement)

DISCUSSION

Because the heterogeneity and compositional variability of mortars and plasters often hinder reliable comparison of their grades (Elsen 2006), the present study identified groups of compositionally homogeneous materials using petrographic and XRD analyses. Grouping was based on differences in semi-quantitative mineralogical composition and macroporosity among the samples. Nevertheless, comprehensive material characterization remains essential for the development of accurate and durable future restoration practices (Marques et al. 2006). Similar approaches have been applied successfully in comparative studies of historic mortars across the Mediterranean basin, emphasizing the importance of microstructural and compositional analysis for understanding degradation patterns and informing conservation protocols (Kakavas, Lycourghiotis, and Kalapodis 2022; Stoyanov, Kostova, and Dumanov 2023).

The Byzantine sample (S.10) suggests continuity of mortar and plaster technology through subsequent phases of occupation. Similar cultural and technological continuities have been identified in the relationship between early Islamic and Byzantine ceramics (Sauer 1986). Such continuity is not limited to ceramics but has also been observed in building tech-

niques across transitional periods in the eastern Mediterranean, particularly in rural settings (Moropoulou, Bakolas, and Bisbikou 2000). Despite the introduction of Portland cement, the inhabitants of Umm Qais continued to use local fillers, as indicated by the presence of basalt clasts, which may reflect a change in craftsmen rather than a complete change in building tradition. These findings support the broader pattern of material continuity in the Levant, where traditional techniques often persisted alongside newer technologies, especially in peripheral, agrarian, and tribal contexts (W.E. Kingery 1988; von Landsberg 1992).

Samples S.3 and S.9, characterized by muddy paste matrices, exhibited the poorest technological properties because of their friability, suggesting a decline in technological knowledge compared with earlier mortars and plasters. The use of muddy plasters during the later occupation phase of the house may be attributed to their lower cost and ease of production. Communities in northern Jordan during this period were primarily engaged in agriculture, whereas specialized handicraft production was often carried out by Syrian craftsmen (Al-Sha'ar 2010).

The relatively high proportion of basalt clasts in many of the samples appears to have been an intentional addition aimed at increasing hardness and reducing permeability (hydraulic cement). This interpretation is supported by the subrounded to angular morphology of the clasts and their generally uniform size of less than 5 mm, which is consistent with the local availability of basalt. These observations suggest that Rooms 1 and 2 were likely constructed during a later phase of occupation. A similar pattern is evident in Rooms 7 and 8, where the floors contain basalt clasts that were probably incorporated before the rooms were constructed. Prolonged occupation of the house by an extended family practicing patrilocal residence would reasonably have required the construction of additional rooms to accommodate newly married members of the household (McCann 1997). At the same time, the use of basalt in plaster was already common during the Roman and Byzantine periods, underscoring both technological continuity and the continued availability of local resources (Al-Bashaireh 2019).

Space syntax analysis revealed clear spatial hierarchies within the house. The courtyard's high connectivity and agent density confirm its role as a social hub, consistent with traditional Levantine domestic architecture in which such spaces facilitated family gatherings and semi-public interactions (Parker 2015; Abdalla and Kafafi 2021). By contrast, the private quarters exhibited low visibility and accessibility values, aligning with Islamic concepts of family privacy and gender segregation (Al-Hussayen 1999; Bianca 2000). The later addition of Rooms 1 and 2, which display different spatial characteristics, may reflect changes in family structure or economic circumstances during the occupation of the house (Rapoport 1980).

Environmental adaptation strategies are evident in both material selection and spatial design. Basalt aggregates provided thermal mass that contributed to climate regulation, while the annual replastering of the roof demonstrates an adaptive maintenance practice (Fathy 1986). The spatial organization of the house optimized

natural ventilation and solar protection, with the courtyard functioning as a climatic moderator (Oliver 2003). Together, these features illustrate how traditional architecture integrated environmental responsiveness with social requirements.

CONCLUSIONS

This study demonstrates the interconnected roles of technology, environmental conditions, and sociocultural structure in shaping the Alrousan courtyard house at Umm Qais. The combined application of material characterization and spatial analysis proved effective for understanding the spatial logic of the courtyard house, revealing continuity in mortar and plaster technology from the Byzantine through the Ottoman period, despite variations in craftsmanship that may reflect declining technical expertise or economic constraints. The results also show that spatial hierarchies were intentionally embedded within the architectural layout, reinforcing traditional Levantine domestic values. Together, these findings highlight the importance of interdisciplinary approaches for the interpretation of historical architecture. The Alrousan house stands as evidence of the adaptive strategies, cultural continuity, and material knowledge of communities in northern Jordan across successive centuries.

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