# Courtyards' Effect on the Sustainability of Archaeological Buildings in Historic Cairo, Egypt

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## Abstract:

Cairo is full of many ancient Islamic buildings that are dated back to successive historical periods extending from the 1st century AH (7 AD) to the 13th century AH (19 AD). The inner courtyard was the central unit in most of these buildings, whether these buildings are religious, civil or military buildings. Courtyard is used for the purposes of ventilation, lighting and providing additional space.

Given the value of these buildings and the need to preserve them in order to achieve sustainable development, this paper aims at studying the effect of inner courtyards in Cairo's archaeological buildings on the preservation and sustainability of these buildings. That could be done by conducting laboratory tests and analysis of archaeological building materials for some of the selected buildings with and without courtyards.

The study relied on the analytical and comparative methodologies to achieve its goal, by comparing samples of the main building materials taken from two archaeological buildings in the Mamluk cemetery, one with a central open courtyard (Qurqumas madrasa) and the other without a courtyard (Qaitbay madrasa), with the samples taken from two archaeological buildings in Al-Moez Street, one with a central open courtyard (Al-Ashraf Bersbay complex) and the second without a courtyard (Suleiman Agha Mosque). Whereas, the analytical method relied on conducting a set of examinations and analysis, including: scanning electron microscope (SEM), X-ray diffraction (XRD), determination of water content ratio (WC), determination of water absorption ratio (WA), analysis by a scanning electron microscope with an elemental analysis unit EDX, and measuring compressive strength (CS).

## Keywords:

Courtyard – Historic Cairo – Islamic architecture – Sustainability – Examination and Analysis - Mamluk cemetery - Al-Moez Street.

## Research importance:

The study is concerned with a new topic that hasn't been covered before, Courtyards' Effect on the Sustainability of Archaeological Buildings in Historic Cairo, Egypt.

## Previous studies:

Parvin and Hassan's [4] study is an important one that dealt with how courtyards are used in modern religious buildings in the third millennium, by making a comparison between ten mosques. The study confirmed that courtyards are among the most important architectural elements that used in mosques after the use of minarets and domes.

DOI: 10.21608/mjaf.2020.46104.1917

While Hamzah [2] presented in his study the importance of courtyards in Islamic buildings as they are the beating heart of them, and his study discussed the origin of their use, especially in hot dry areas as one of the climate treatments. The study also discussed the effect of the absence of courtyards on modern buildings as a result of design and planning variables, which make the courtyard has a negative effect to provide thermal comfort to users.

Vida [5] presented the historic development of using open courtyards in ancient buildings since ancient times, and his study indicated that this development has passed through different stages in shape, dimensions and nature of use.

The paper conducted by Nik and others [1] aimed to study the landscape means in the design of the courtyard by making a comparison between the house of Suhaymi in Cairo and the Alhambra palaces in Granada, to determine the characteristics of landscape in Islamic courtyards through the use of water, the reflection of the sky and the environmental control.

All the above-mentioned studies dealt with the effect of the courtyard element on the users, but none of them dealt with the different effects of the courtyard on the archaeological building itself, so the study came to clarify this effect.

## 1. Introduction:

The courtyard is the central unit in most of ancient Islamic buildings, its design is a square or a rectangle, open or covered space and surrounded by buildings [1]. It is of multi functions; The first, is to afford space for meeting of all users, according to the function of the building itself [2] whether in religious buildings (mosques - khaniqa - madrasas), civil buildings (houses - palaces - wikala – bimarstan or hospital), or military (castles – forts) [3]. The second, is to isolate the building from noise and surrounding outdoor activities [4]. The third, is to stand as one of the means for climate treatment, especially in hot areas; for lighting and ventilation by storing cold air at night and then emitting it during the day to resist the hot temperature [3]. The study carried out by Makani [5] also indicated that the courtyard has an important role in Islamic buildings, and reducing this role in contemporary buildings has led to a deterioration of spatial quality.

In the case of dealing with archaeological buildings, there is a need to preserve it, and there is a close relationship between preservation and sustainable development, as preservation is considered one of the means to achieve environmental, social and economic development, and thus to achieve sustainable development [6].

But a question arises: is the presence of courtyards in archaeological buildings a positive factor that helps to sustain and preserve these buildings and transfer their values to future generations? or does it negatively affect the archaeological buildings by enabling the direct effect of deterioration factors, represented by the effect of some natural factors such as wind, moisture, sunlight, and air pollution gases, and in this case, effective and innovative solutions should be proposed taking into consideration the nature and values of these buildings.

To study the effect of the courtyards on the sustainability of the archaeological buildings in historic Cairo, a comparison was made between the archaeological buildings of an open courtyard and those without a courtyard to assess the positive or negative effect of the open courtyard on the sustainability of these buildings.

Therefore, four archaeological buildings were chosen in two different locations, the Mamluk Cemetery and Al-Moez Street area (Fig.1). The nature of the two regions differs slightly in terms of their topography and the historical periods to which the buildings in these two regions return.

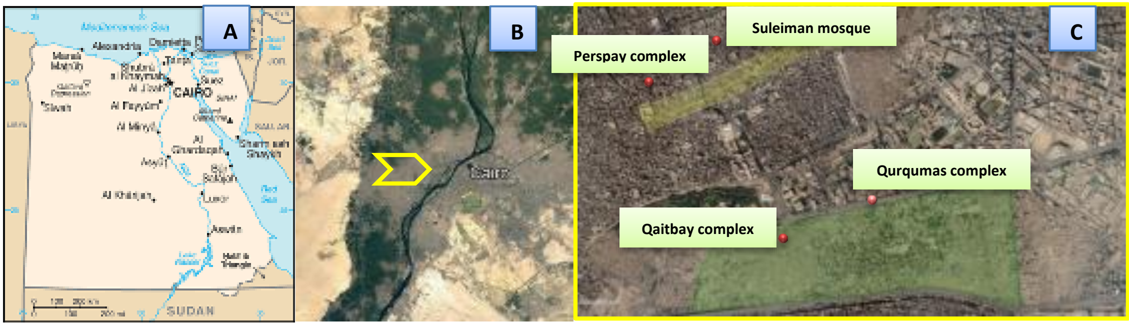



**Fig. 1. (a) Site of Cairo city on Egypt map [10], (b) Detail from the previous image (Google earth application), (c) The boundaries of the Mamluk cemetery and Al Moez Street (Google earth application)**

## 1.1. Studied Buildings:

A comparison was made between two archaeological buildings in the Mamluk Cemetery, one with an open courtyard (Qurqumas Madrasa) and the other without a courtyard (Qaitbay Madrasa) (Fig.2), as well as two buildings on Al-Moez Street, one with an open courtyard (Al-Ashraf Perspay complex) and the second without a courtyard (Suleiman Agha Mosque) (Fig.3).

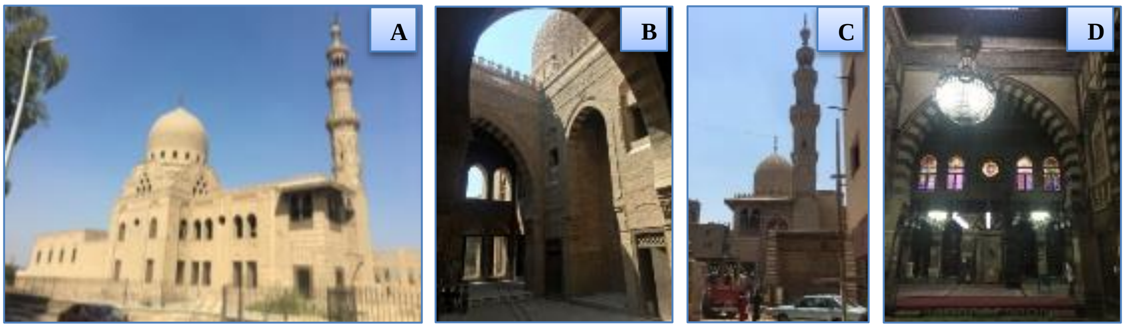



**Fig. 2. (a) Qurqumas complex, (b) Qurqumas Madrasa's inner open court, (c) Qaitbay complex, (d) Qaitbay Madrasa's inner court (both in Mamluk Cemetery), Source: survey by the authors.**

**Fig.3. (a) Al-Ashraf Perspay complex, (b) Perspay madrasa's inner open court, (c) Suleiman Agha Mosque' s inner court, (d) roofing system of the inner court (both in Al-Moez Street), Source: survey by authors.**

The studied buildings are dated back to different historical period; Qurqumas Madrasa (913 AH / 1507 AD) is located at the northern end of the Mamluk Cemetery and it is 600 meters away from Qaitbay complex (879 AH / 1474 AD). Al-Ashraf Perspay complex (829 AH / 1425 AD) is located in a part of Al-Moez Street, known as Al-Ashrafia and it is 500 meters away from Suleiman agha mosque (1255 AH / 1839 AD), which its inner ventilation was derived from some windows and the use of the Malqf which is located on the tops of the building, with an opening to entrap the cooler air [7].

## 2. Materials and Methods:

### 2.1. Sampling:

This study was conducted by carefully taking eight (8) small samples (two different samples from each site) of the main building material from the studied buildings (Table 1), especially from the courtyard area.

Table 1. The codes, sites and type of courtyards for the studied samples

| Code | Monument's name | General site | Courtyard's type | Taken samples | |
|---|---|---|---|---|---|
| A | Qurqumas Madrasa | Mamluk Cemetery | Open | A.1 | A.2 |
| B | Qaitbay Madrasa | | Closed | B.1 | B.2 |
| C | Perspay madrasa | Al-Moez Street | Open | C.1 | C.2 |
| D | Suleiman mosque | | Closed | D.1 | D.2 |

### 2.2. Analytical Methodology

Analysis and examinations of main building materials reveal much information about their components and their state of deterioration, which in turn indicate their sustainability. To achieve these objectives, samples were collected, examined and analyzed by the following methods.

2.2.1 Examination Methods

2.2.1.1 Scanning Electron Microscopy (SEM): The microstructure of the studied samples was investigated via SEM (Fig.4) to assess morphological features by a Quanta FEG 250 scanning electron microscope (FEI, Netherlands). The magnification on the studied samples ranges from 1500 to 6000x and the accelerating voltage was 20 kV.

- Scanning Electron Microscopically; Examination not only provides a detailed microstructure and 3D morphology of stones and mortars at a very high magnification but also provides an elemental composition of the area of interest.

2.2.2 Analysis Methods

The collected samples were investigated by mineralogical, physical and mechanical analyses.

2.2.2.1 X-ray Diffraction Method (XRD): It was used for characterizing the mineralogical composition of samples by using X-Ray diffraction equipment with monochromator, cu-radiation at 45 K.V., 35 M.A. and scanning speed 0.03 °/sec. were used.

2.2.2.2. Scanning Electron Microscopy Provided with EDX: The FEG Quanta 250 is equipped with an energy dispersive spectrometer for elemental analysis on a microscopic scale.

2.2.2.3 Water Content (WC) (%): At Atmospheric Pressure.

2.2.2.4 Water Absorption (WA) (%): At Atmospheric Pressure.

2.2.2.5 Compressive Strength (CS): preparing samples that simulate the archaeological samples to perform the compressive strength and determine the coherence of the archaeological building materials in each site. Determination of CS: ASTM C170 2009 by using 3000 KN soil test universal testing machine model OT-b200-8.

# 3. Results and Discussion

## 3.1. Examination and Analysis Results

3.1.1. Scanning Electron Microscopy Results:

SEM micrographs of the investigated samples (Fig. 4, 5, 6 and 7) are characterized by the erosion of stone crystals due to the influence of humidity, in addition to the strong influence of weathering factors affecting the stone from its surface and continuing inwards, thus losing the mineral fabric.

As for the samples from the Mamluk Cemetery (fig. 4 and 5); the samples from open courtyard were more affected than the others from closed courtyard. In Al-Moez Street; the samples that were taken from the open courtyard are better than other samples from the closed courtyard, as the cracks and gaps have decreased. The results indicate that the samples taken from the Mamluk Cemetery were in better condition than the samples from Al Moez Street (Fig.6 and 7). On the other hand, EDX micro analysis indicates that all of the samples are characterized by the same characteristic elements as Ca, S, Si, O were observed as major elements.

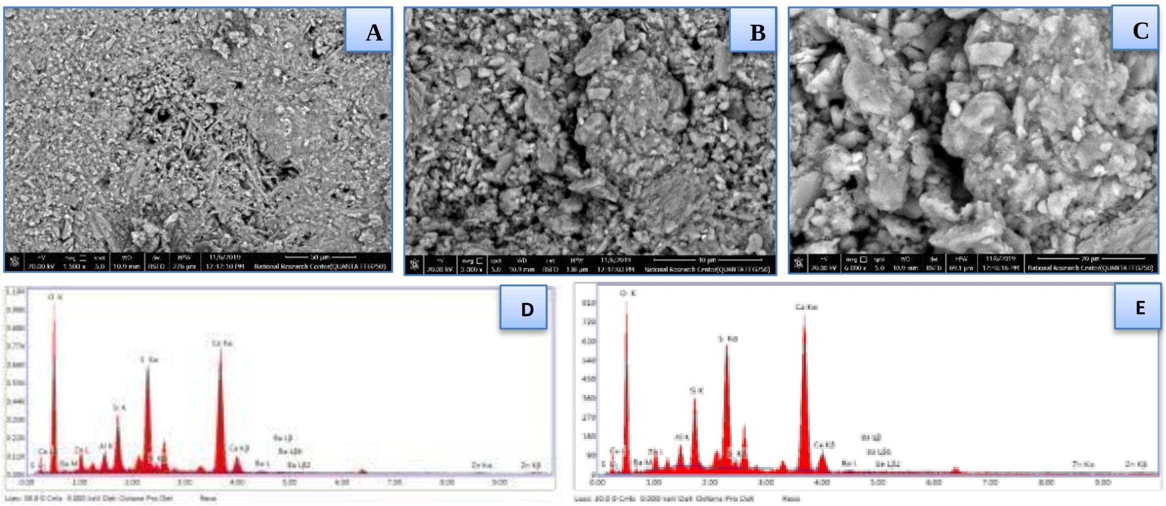



**Fig.4. (a) SEM microscopic examination and micro structure at 1500X, (b) SEM micrograph at 3000X, (c) SEM micrograph at 6000X, (d), (e) EDX spectrum from the previous images of limestone grains from Qurqumas Madrasa's open courtyard, a strong calcium signals are observed.**

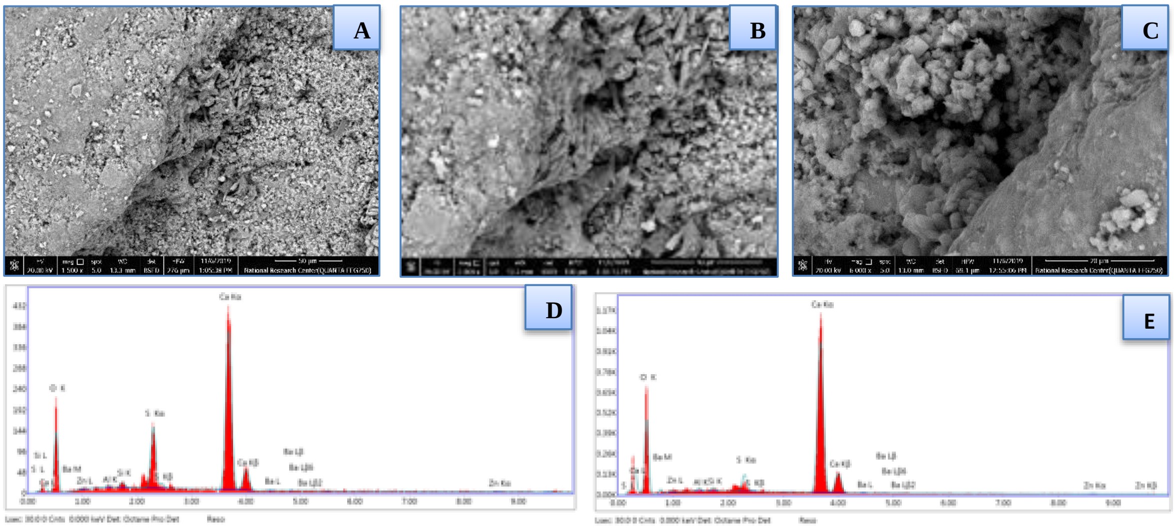



**Fig.5. (a) SEM microscopic examination and micro structure at 1500X, (b) SEM micrograph at 3000X , (c) SEM micrograph at 6000X, (d), (e) EDX spectrum from the previous images of limestone grains from Qaitbay Madrasa's closed courtyard, a strong calcium signals are observed.**

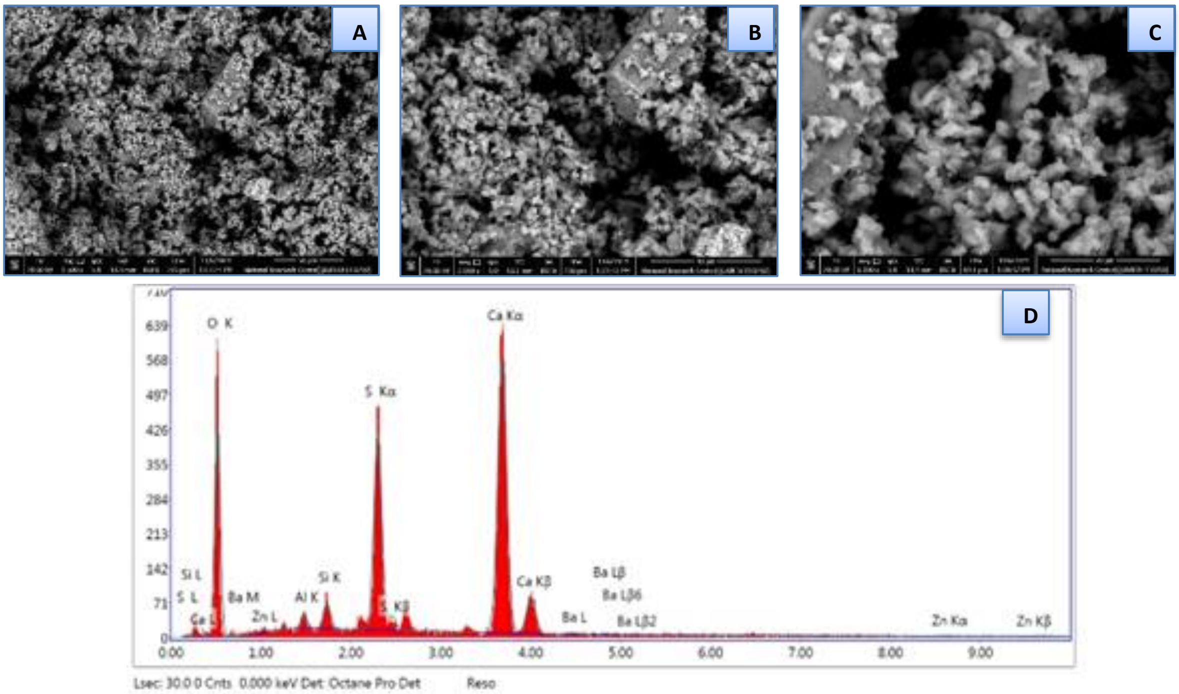



**Fig.6. (a) SEM microscopic examination and micro structure at 1500X, (b) SEM micrograph at 3000X , (c) SEM micrograph at 6000X, (d) EDX spectrum from the previous images of limestone grains from Perspay madrasa's open courtyard, a strong calcium and sulfur signals are observed.**

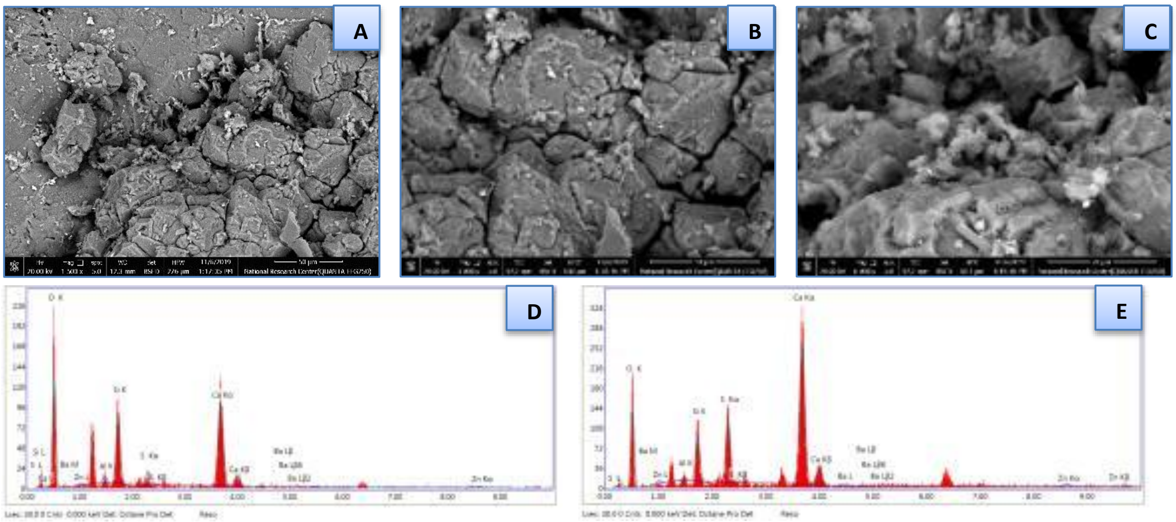



**Fig.7. (a) SEM microscopic examination and micro structure at 1500X, (b) SEM micrograph at 3000X , (c) SEM micrograph at 6000X, (d), (e) EDX spectrum from the previous images of limestone grains from Suleiman mosque's open courtyard, a strong calcium and silicon signals are observed.**

### 3.1.2. X-ray Diffraction Results:

Results of the XRD analysis for the main building materials at the four studied buildings are shown in (Table 2) and in (Fig.8). The results of x-ray diffraction confirm the results of the examination obtained by scanning electron microscope. They indicate that the composition of the four samples are:

- Sample A. (major calcite $CaCO_3$ + minor gypsum $CaSO_4 .2H_2O$, quartz $SiO_2$ + traces Dolomite $CaMg(CO_3)_2$ ).
- Sample B. (major calcite $CaCO_3$ + minor Quartz $SiO_2$).
- Sample C. (major calcite $CaCO_3$ + minor Quartz $SiO_2$).

- Sample D. (major Dolomite $CaMg(CO_3)_2$ + minor Quartz $SiO_2$).

From XRD analysis, it's noticed that, calcite $CaCO_3$ was detected in the three first samples (A, B and C) which are dated back to the Mamluk period as a major component, while Dolomite $CaMg(CO_3)_2$ was detected in the fourth sample (D) which is dated back to the Ottoman period as a major component. The origin of dolomite is chemically transformed from a pure calcium limestone after deposition and burial [8].

That's beside gypsum $CaSO_4 .2H_2O$ and quartz $SiO_2$ as minor components. This result makes the comparison clearer as the four samples have a similar chemical composition.

Accordingly, the difference in the state of the stones in the four archaeological buildings depends mainly on the variation between temperature and humidity, and also on the nature of the region in which these buildings are located.

**Table 2. Minerals Identified in the Main Building Material for the Studied Samples by XRD Analysis**

| No. | Samples | Minerals | Formula | Index No. |
|---|---|---|---|---|
| **A** | Lime stone from open courtyard | Calcite<br>Gypsum<br>Quartz<br>Dolomite | $CaCO_3$<br>$CaSO_4 .2H_2O$<br>$SiO_2$<br>$CaMg(CO_3)_2$ | 01-072-4582<br>00-006-0046<br>01-078-2315<br>00-036-0426 |
| **B** | Lime stone from closed courtyard | Calcite<br>Quartz | $CaCO_3$<br>$SiO_2$ | 01-072-4582<br>01-078-2315 |
| **C** | Lime stone from open courtyard | Calcite<br>Quartz | $CaCO_3$<br>$SiO_2$ | 00-024-0027<br>01-078-2315 |
| **D** | Lime stone from closed courtyard | Dolomite<br>Quartz | $CaMg(CO_3)_2$<br>$SiO_2$ | 01-075-3686<br>01-085-1054 |

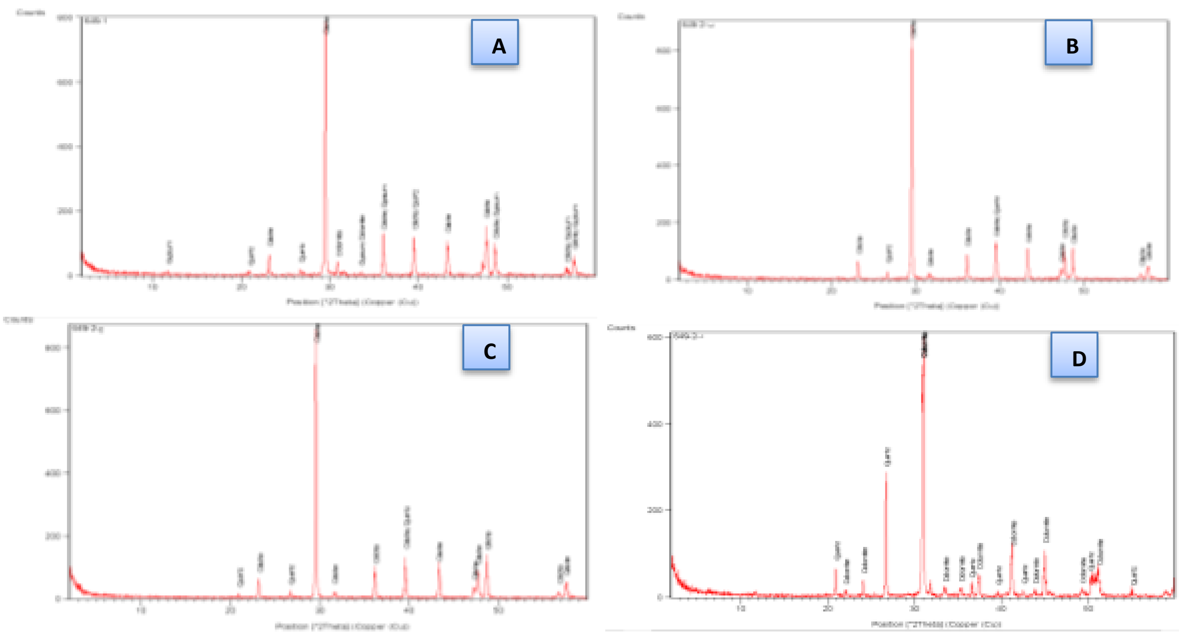



**Fig.8. X-ray Patterns of the Identified Minerals in the Main Building Material for the Studied Samples A, B, C and D**

3.1.3. Results of Water Content Test:

The water content of the studied samples was calculated by weighing and drying at a temperature of 110 ° C and at atmospheric pressure for 3 days at a rate of two hours per day then re-weighing them and recording the dry weight. Therefore, it was possible to calculate the water content of the samples from the following equation:

**Percentage of water content** = **Weight before drying - Weight after drying / Weight after drying** × **100**

An average of water content for two samples from one site was calculated to express the water content of each site (Table 3, Fig.9).

From its results, it is noticed that, the high percentage of water content of the two samples taken from Perspay Mosque (open courtyard) and Suleiman Mosque (closed courtyard) in Al-Moez Street from their counterparts in the Mamluk Cemetery and the percentage of water content in the Qaitbay Mosque (closed courtyard) is higher than that of Qurqumas Mosque (open courtyard), which are located in the Mamluk Cemetery by 0.14 % .

The percentage of water content in the Suleiman Agha Mosque (closed courtyard) is higher than that of Al-Ashraf Perspay Mosque (open courtyard), which are located in Al-Moez Street, by 2.92 %, so we can conclude that the high percentage of water content in archaeological buildings with closed courtyards than in archaeological buildings with open courtyards.

**Table 3. Indicates the Average of Water Content in the Studied Samples**

| Sample No. | Weight before drying (gm) | Weight after drying (gm) | Percentage of water content (%) | Average of water content (%) |
|---|---|---|---|---|
| **A.1** | 41.14 | 40.80 | 00.85 | 0.69 |
| **A.2** | 64.65 | 64.31 | 00.53 | |
| **B.1** | 50.73 | 50.46 | 00.54 | 0.83 |
| **B.2** | 22.03 | 21.79 | 01.11 | |
| **C.1** | 19.53 | 19.31 | 01.18 | 1.95 |
| **C.2** | 02.97 | 02.90 | 02.72 | |
| **D.1** | 07.84 | 07.79 | 00.74 | 4.87 |
| **D.2** | 01.22 | 01.12 | 09.01 | |

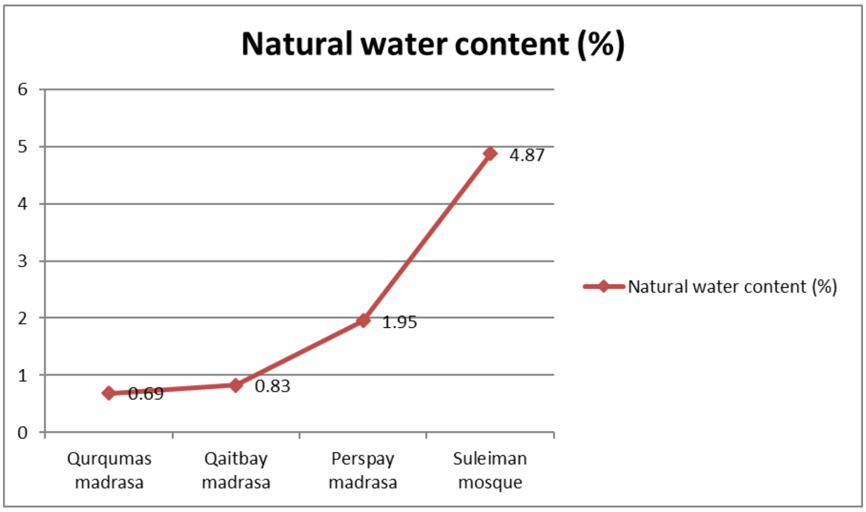



**Fig.9. Indicates the Average of Water Content in the Studied Samples, as Qurqumas and Perspay madrasas with open courtyards, while Qaitbay madrasa and Suleiman mosque with closed courtyards.**

3.1.4. Results of Water Absorption Test:

This experiment comes to be a complement to what was before, after calculating the natural content of water, the ratio of water absorption for the studied samples was calculated in order to know the response of each sample to absorb the water if conditions were available for that, and accordingly the samples were immersed into water for three days, then weighed to calculate the difference in weight before and after immersion (Table 4, Fig.10), this was according to the following equation, at atmospheric pressure,

**Percentage of water absorption = Wet weight – dry weight / Dry weight × 100**

From water absorption test, it's noticed that the samples taken from the Mamluk cemetery: Qurqmas madrasa (open courtyard), recorded the highest absorption rate (4.77%), than the samples that were taken from the Qaitbay madrasa (closed courtyard), which recorded ( 0.92%) of water absorption, while the percentage of water absorption in the Suleiman Mosque (closed courtyard) is higher than that of Perspay Madrasa (open courtyard), which are located in Al-Moez Street.

As a result of the water absorption test, samples from open courtyard in Mamluk cemetery suffer from deterioration as it recorded the highest absorption rate, while the sample from open courtyard in Al-Moez street has good environment of preservation as it recorded the lowest absorption rate.

**Table 4. Indicates the average of water absorption of the studied samples**

| Sample No. | Dry weight (gm) | Wet weight (gm) | Percentage of water absorption (%) | Average of water absorption (%) |
|---|---|---|---|---|
| **A.1** | 40.80 | 43.47 | 06.55 | 4.77 |
| **A.2** | 64.31 | 66.23 | 02.99 | |
| **B.1** | 50.46 | 51.18 | 01.43 | 0.92 |
| **B.2** | 21.79 | 21.87 | 00.40 | |
| **C.1** | 19.31 | 19.34 | 00.18 | 0.59 |
| **C.2** | 02.90 | 02.929 | 01.00 | |
| **D.1** | 07.79 | 07.83 | 00.51 | 1.05 |
| **D.2** | 01.12 | 01.13 | 01.60 | |

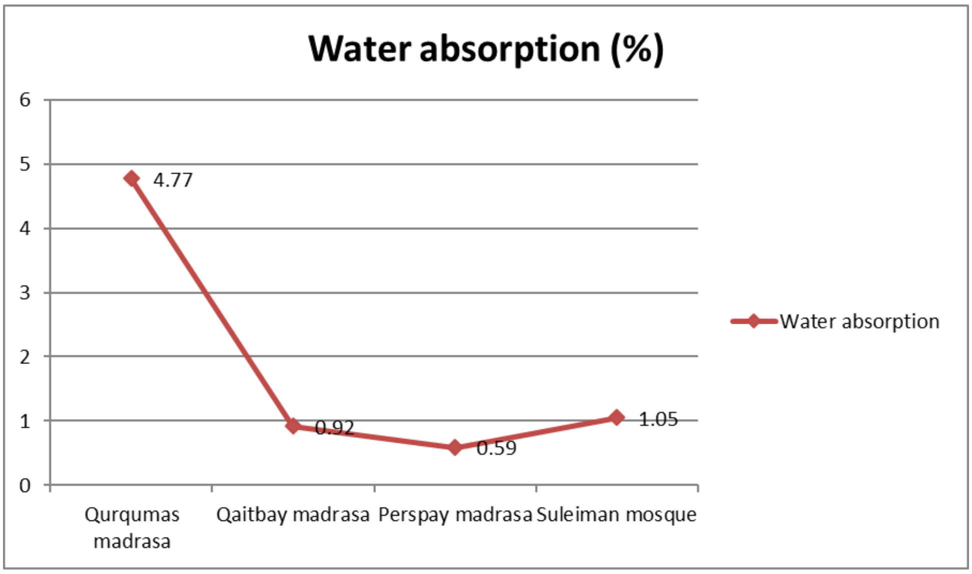



**Fig.10. indicates the average of water absorption of the studied samples**

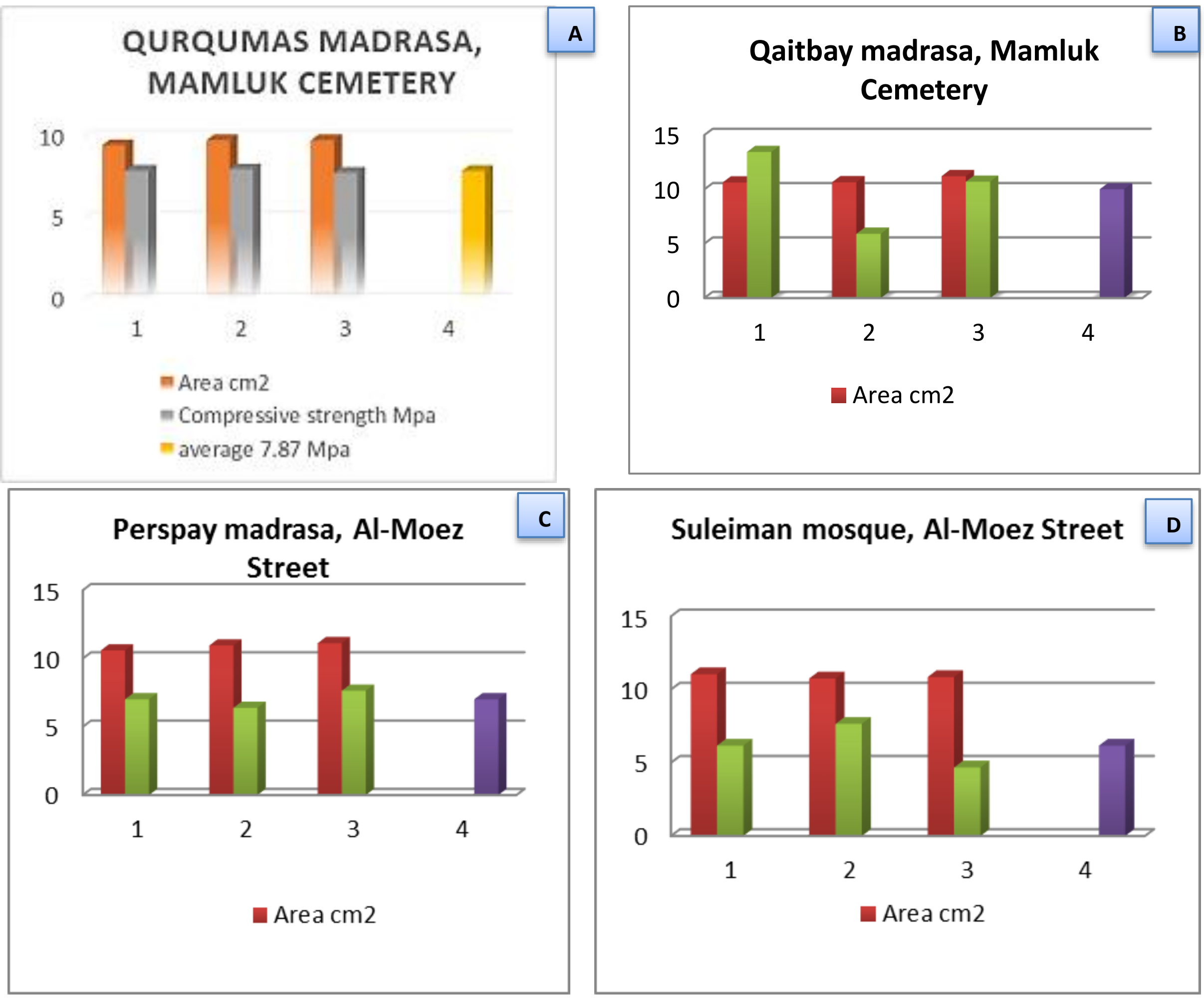
3.1.5. Results of Compressive Strength Test:

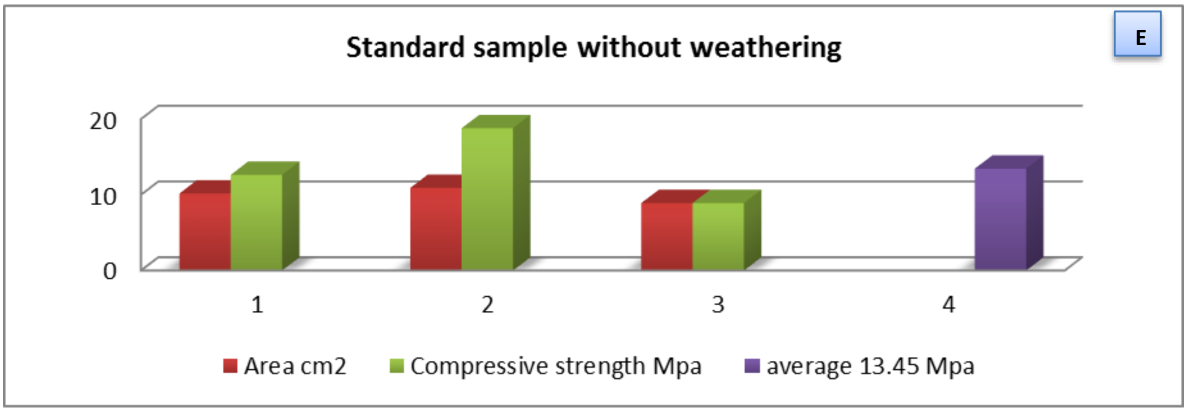
The compressive strength is distinguished as the maximum load per unit area which the stone can bear until failure [9], it is based on the natural content of water, this experiment was set to determine which of samples has the ability to compressive strength in the presence of water.

Twelve samples of limestone were prepared ( approximately 3×3×3 cm), compressive strength was measured and then compared with that for Standard sample of limestone without weathering (Fig.11).

From the compressive strength test's results, it is noticed that; Samples from the Mamluk Cemetery recorded a higher compressive strength than the samples from of Al Moez Street depending on the natural water content for these samples. The percentage of compressive strength for the samples from closed courtyard is higher than that from open courtyard in the Mamluk cemetery, while the percentage of compressive strength for the samples from closed courtyard is less than that from open courtyard in Al-Moez Street.

Also the higher compressive strength - comparing to the standard sample- was for Qaitbay madrasa's sample (closed courtyard) in the Mamluk cemetery, and the less compressive strength – comparing also with the standard sample- was for Suleiman mosque's sample (closed courtyard) in Al-Moez street.





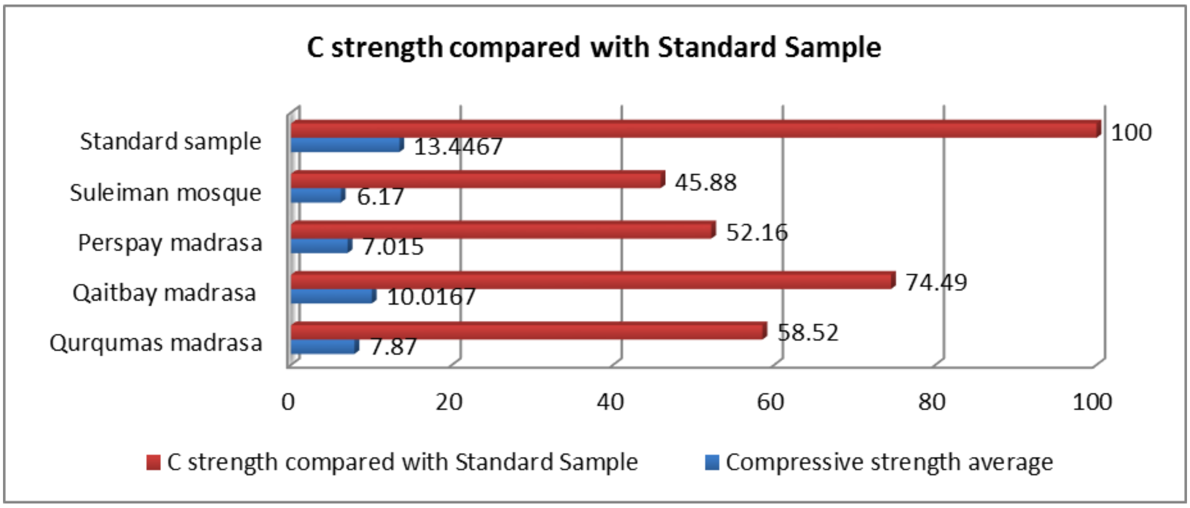




**Fig.11. (a), (b), (c), (d) indicate the results of compressive strength test for the four studied buildings , (e) the results of the test for the standard sample, (f) the compressive strength for the average of four samples compared with standard samples.**

## 4 Conclusions

The studied archaeological buildings, located in the Mamluk Cemetery, are better preserved than their counterpart on Al-Moez Street, this is due to this site's dry nature. Therefore, the nature of the site is an influencing factor that enhances the role of the courtyard in the sustainability of the archaeological buildings.

Archaeological buildings with closed courtyards in dry areas such as the Mamluk Cemetery are higher in compressive resistance than archaeological buildings with open courtyards. This is because of the control of temperature differences and less effect of moisture factors, (Temperatures are the main controller), thus the absence of courtyard increases the thermal isolation for buildings, especially in desert areas.

Archaeological buildings with open courtyards in populated areas with high humidity are higher in compressive strength than the archaeological buildings with closed courtyards that suffer from high humidity and weak stones. (Moisture is the main controller). The presence of courtyards helps in ventilation, so that it is a better preservation environment that helps the sustainability of the buildings, so we can conclude that the influence of the courtyard depends on the nature of the site which the archaeological building is located on and its local and climatic environment.

The study recommends the necessity of shading and covering the courtyards in dry places to avoid the effects of temperature variation, and ventilating closed courtyards in populated areas that suffer from high humidity.

**Acknowledgments:**
The authors would like to show their gratitude to the Ministry of Antiquities, the Islamic Monuments' Sector, in the Mamluk cemetery and Al-Moez Street for sharing their support in the field work.

**Funding:**
This research did not receive any specific grant from funding agencies in the public, commercial, and it is not-for-profit sectors.

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