INTERNATIONAL JOURNAL
OF
CONSERVATION SCIENCE
ISSN: 2067-533X Volume 14, Issue 2, April-June 2023: 399-416 www.ijcs.ro
DOI: 10.36868/IJCS.2023.02.02

INGENIOUS RAINWATER HARVESTING SYSTEM WITHIN THE ALGIERS OTTOMAN RESIDENTIAL BUILDINGS (RECONSTITUTION AND PERFORMANCE ASSESSMENT)

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Abstract

This article deals more particularly with the architectural reconstitution and the hydraulic checking of the rainwater harvesting system (RWH-system) installation in some residential buildings in Ottoman Algiers (16th to 18th centuries), where this water was intended for various domestic uses. This work was applied to two cases (Khdawedj-El'Amia and Hassan-Pasha palaces). An architectural reconstitution by three-dimensional modeling was made based on investigations and bibliographic research on the system. In contrast, hydraulic verification was made according to the current European sizing standards based on rainfall records for over 100 years. The results indicate that these buildings are equipped with an innovative and efficient hydraulic system based on relativity between rain, roof, and stored volume (djeb), according to current standards; this system has the potential to meet the needs of the populations and ensure their water autonomy, particularly in times of water scarcity.
And consequently, rainwater management in a secure way. On the other hand, the results assess the possibility of returning the RWH system to function today. It provides helpful information to develop an action plan and intervention strategies for restoring the (RWH-system) in the heritage residential buildings for improving sustainability and maintaining the built heritage values of the historic Ottoman Algiers.

***Keywords**: Ottoman Algiers; Architectural heritage; Rainwater harvesting (RWH); Cistern (djeb); Current hydraulic standard; Reliability; Restitution*

Introduction

Rainwater harvesting systems have been used since ancient times, similar to rooftop catchment systems that date back to early Roman times. Since at least 2000 BC, Roman villas and towns have been deliberately constructed to utilize rainwater as their main source of water for household use [1]. In the Negev Desert (Jordan and Palestine now), reservoirs to store runoff from hillsides for domestic and agricultural purposes have enabled habitation and cultivation in areas with as little as 100 mm of rain per year [2]. The first known evidence of the technology being used in Africa comes from northern Egypt, where reservoirs ranging from 200-2000m^3 have been used for at least 2000 years, many still operational today [3].

Rainwater harvesting also has a long history in Asia, where its practices date back nearly 2000 years to Thailand. Small-scale rainwater collection from roof gutters or through a simple gutter into traditional pots which has been practiced in Africa and Asia for thousands of years.

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In many remote rural areas, this method is still used today. The probably largest rainwater reservoir in the world is that of Yerebatan Sarayi in Istanbul, Turkey. This was built during the reign of Caesar Justinian (527-565 AD). It measures 140 m by 70 m and has a capacity of 80.000 m^3 [4].

The architectural aspects and building materials of the Ottoman era in several countries, especially in Algeria, have been the subjects of several works. However, the hydraulic side has been the least studied, as has the water supply system, composed of components comparable to current hydraulic systems. Although the current hydraulic laws were not well understood at the time.

Several research projects related to the water supply in Algiers during the Ottoman period, guaranteed by a public network of highly efficient aqueducts, have been the subject of several historiographical and archaeological studies. These include *E. Pasquali* [5, 6] on the evolution of the water supply in Algiers and its influence on the development of public sanitation; *M. Belhamissi* [7] on the history of Algiers through its water supply; *F. Cresti* [8, 9] on the water system in Algiers and its aqueducts; *S. Chergui* [10] on the contribution of the Moors to the construction of Algiers and the reinforcement of its hydraulic networks; *A. Boudjelida* [11] on the obtaining and distributing water in houses of the kasbah, Algiers between tradition and innovation; *A. Khalassi* [12] and *N. Razougue* [13] on the citadel of Algiers and its water supply. Other urban and architectural research has also addressed this question. These include *N. Cherif-Seffadj* [14, 15] on the baths in Algiers and their water supply; *D. Ouzidane* [16-18] on the network of aqueducts and founts in Algiers; and last but not least, H. Tahari [19, 20] and *H. Tahari and T. Kassab* [21] on the recovery of rainwater in Algiers based on its topography. Some of these publications have contributed significantly, as part of the PPSMVSS 2003 (Permanent Plan for the Safeguard and Enhancement of the Safeguarded Sectors), to the restoration of water supply networks dating from the Ottoman period, as well as all other elements of hydraulic nature marked on maps.

Other research has treated the old rainwater harvesting system and its historical models, such as the study of *L. Mays et al.* [22] about the history of water cisterns; *P. Laureano* [23]. Water Conservation Techniques in Traditional Human Settlements; *G. Antoniou et al.* [24]. Historical development of technologies for water resources management and rainwater harvesting in the Hellenic civilizations. Many other recent studies on the technical aspect of the system and its performance and reliability appear in the bibliography and collected in the study entitled "Optimal sizing of rainwater harvesting systems for domestic water usage: A systematic review of the literature" by *M. Semaan et al.* [25].

This study specifically addresses the technical and functional aspects of the rainwater harvesting systems installed in Ottoman houses in Algiers, which currently suffer from a degradation of their built environment and sanitary conditions, and consequently, their dysfunction, because they have undergone transformations during the colonial and post-colonial periods, as a result of inappropriate uses and sometimes after abandonment. To restore the system's original installation, see its design's particularity in vernacular architecture, and identify all its components with architectural restitution, to show how this system participates in rainwater management in this kind of architecture. Then we aim to examine the performance of this old installation with current hydraulic calculation standards.

This study can be integrated with many of the current research that helps to consider the exploitation of rainwater and its storage, like the study titled Stormwater as an alternative water source by *A. Pieniaszek* [26], which can participate in the use and development of standards for water reuse. It is also considered one of the types of research that deals with the conservation of historical buildings currently. It allows an assessment of their preservation status and function according to current standards, as in the case of the study of *W. Hamma* and *A.I. Petrişor* [27] titled Assessing the restoration of *Sidi el benna* mosque in Tlemcen (Algeria).

Water System in Ottoman Algiers

During the Ottoman period (16th-18th century), Algiers was supplied with water by different techniques, such as at the urban scale by constructing aqueduct networks [18], which brought water from the hills to the many sources of the river. City, ensuring its hygiene measures (Fig. 1).

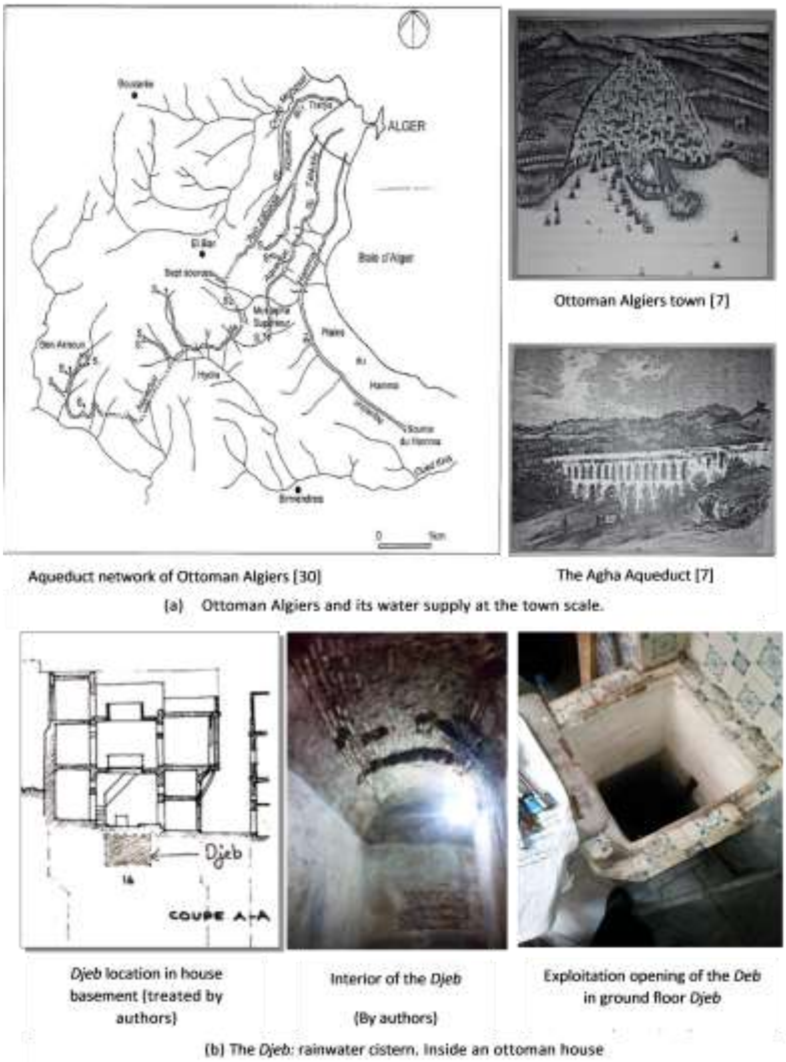
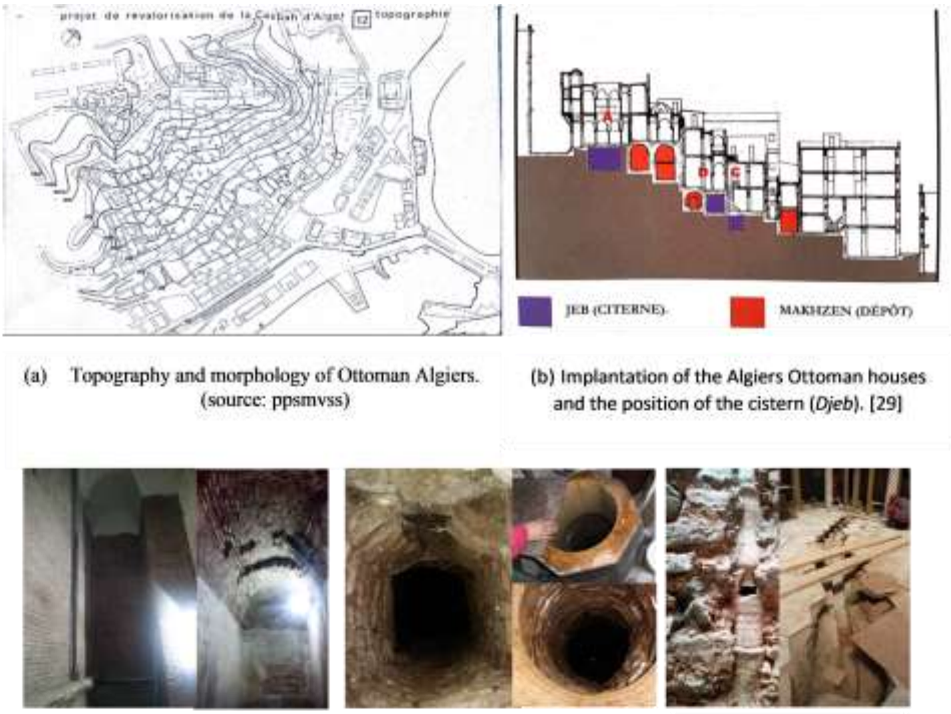


Fig. 1. Water supply in Ottoman Algiers

However, this water supply system is no longer sufficient to meet the demands of an ever-growing population [5, 28]. For this reason, other water sources, such as groundwater and rainwater, have been used by the construction of wells and rainwater cisterns on the architectural scale of houses, where most have wells (*Bîr*) and rainwater cisterns (*Djeb*) placed in their basements (Fig. 1b). In addition to a manual filling jar built into the wall at the level of the *Sqifa* or the patio. Ottoman Algiers comprises two distinct topographical entities: the upper town, called the *Djbel*, built on a steep slope, and the lower plateau, near the sea, called *outa*, on a gentle slope (Fig. 2a).



(a) Topography and morphology of Ottoman Algiers. (source: ppsmvss)

(b) Implantation of the Algiers Ottoman houses and the position of the cistern (*Djeb*). [29]

Masonry vaults and walls of the *Djeb* with solid brick

The *Djeb* and the well opening with solid brick

Downspouts and gutters in terracotta

(c) Structure of the water tank (*Djeb)* and of the well/ downspouts/ gutters Source: authors

Fig. 2. Relation between the topography of Ottoman Algiers, the implantation of the Algiers Ottoman houses, and the position of the cistern (*Djeb*).

A specific relationship exists between installing the cistern (*Djeb*) in these houses' basements and the site's steeply sloping topography. The houses are interconnected one with the other so that they compensate for the steeply sloping terrain. Storage facilities and cisterns *(Djeb)* are built under the patio or the other living spaces. These installations and storage rooms in the basement are entirely vaulted [29], which gives the house a level and solid foundation on which to stand (Fig. 2b). Because the houses are tightly interlinked within the same urban entity, their terraces form a large surface for rainwater catchment. However, the presence of the ad-hoc *Djeb* in the interior of each house allows each of the terraces to evacuate rainwater separately to the cistern (*Djeb*) to which it is attached.

The dual functionality of the *Djeb* as both a foundation for the house and a rainwater cistern is ensured by its massive brick and stone masonry structure, bonded with a lime mortar. They are the type of walls, usually more than 80 cm thick, that can support vaulted masonry ceilings made of brick. Their interior walls, which are in direct contact with the water, are covered with an impermeable coating called (signinum opus) composed of quicklime, sand, broken tiles (minutely crushed fragments of tiles or brick), and wood ash, which is kneaded with wooden mallets for three consecutive days and nights, while water and oil are added alternatively until the required consistency is reached [31-33].

Rainwater flows into the cistern (*Djeb*) from vertical downspouts composed of cylindrical terracotta elements fitted inside the other, with their joints strengthened by a sealant. These downspouts are related to gutters made of brick installed horizontally [34] (Fig. 2c).

Experimental part

Study case

The choice of case study is made based on fieldwork after having visited more than 120 buildings between modest houses, large mansions, and palaces, which are classified according to the installation of water systems into three categories:

(1) House with a rainwater cistern (*Djeb*) (rainwater harvesting systems);

(2) House with well (underground water supply system);

(3) House with well and cistern (*Djeb*) (two adjacent systems: one for the supply of underground water; the other for rainwater harvesting).

Based on this classification, we chose two cases of different sizes from the third category to gain a clear and synthetic idea about the cistern installation (*Djeb*) and its relationship with the well.

- The palace of Khdawedj-El'Amia, with both well and adjacent cistern (*Djeb*), where the *Djeb* is installed in the basement.
- The palace of Hassan-pacha, a palace with both well and adjacent cistern (*Djeb*), where the *Djeb* is installed on the ground floor.

The Palace of Khdawedj-El'Amia

The Palace of *Khdawedj-El'Amia* is located in the Lower Casbah, in the heart of the Souk-El-Djemaa District, along with the present-day Mohamed Akli Malek road [35]. This mansion, dating from 1570, is five stories high and is an example of palatial architecture characterized by a central arrangement of its rooms around a patio. The basement contains the bulk of the *Djeb* and the well. At the same time, on the ground floor, we found the main entrance, the Sqifa, and some service spaces, which are superimposed on the first floor by bit Es'saboune a laundry room that contains the exploitation openings of the *Djeb* and well. The first floor also houses an average-sized patio, giving access from a series of galleries to four living rooms. The layout of the second floor is the same. The third floor is partly occupied by the two rooms of the belvedere (*Manzeh*), and the terraces above these two rooms, and on a level with them, make up the rainwater catchment surface. They are linked to two downspouts that evacuate the rainwater towards the *Djeb* (Fig. 3a).

During the French occupation, the *Khdawedj-El Amia* palace had undergone several transformations both within and around the edifice, including the destruction of small neighboring houses (*douirettes*) so that a new extension could be built in their place. It was classed as a historical monument in 1887. Today, Khdawedj-El'Amia palace is the home of the Museum of Art and Popular Tradition, and as such, it benefitted from rehabilitation work in 2003. At present, the *Djeb* has been converted into a museum storeroom.

The Palace of Hassan-Pacha

The Palace of *Hassan-Pacha* is situated in the Lower *Casbah*, at the intersection of Bouzrina Road with Hadj Omar Road. Built-in 1791, it reflects palatial architecture with a residential character. It is six stories high and stands adjacent to the Ketchawa Mosque, opposite Dar Aziza [35]. The ground floor, accessible from the main monumental entrance, houses the reception area, water closets, and installations, such as the well and cistern (*Djeb*). The *Djeb* rises to the first floor, which adjoins other service spaces, such as the kitchen and laundry. On the second floor, a huge patio partially overhangs the *Djeb*, with living rooms on all its sides that open onto galleries. This same layout of living rooms built around a patio is repeated up to the fourth floor. The two final floors are occupied by a belvedere (Menzah) and part of a terrace that, together with the roof of the Menzah, forms the rainwater catchment surface. Four downspouts carry rainwater collected to the *Djeb* [36] (Fig 3b).

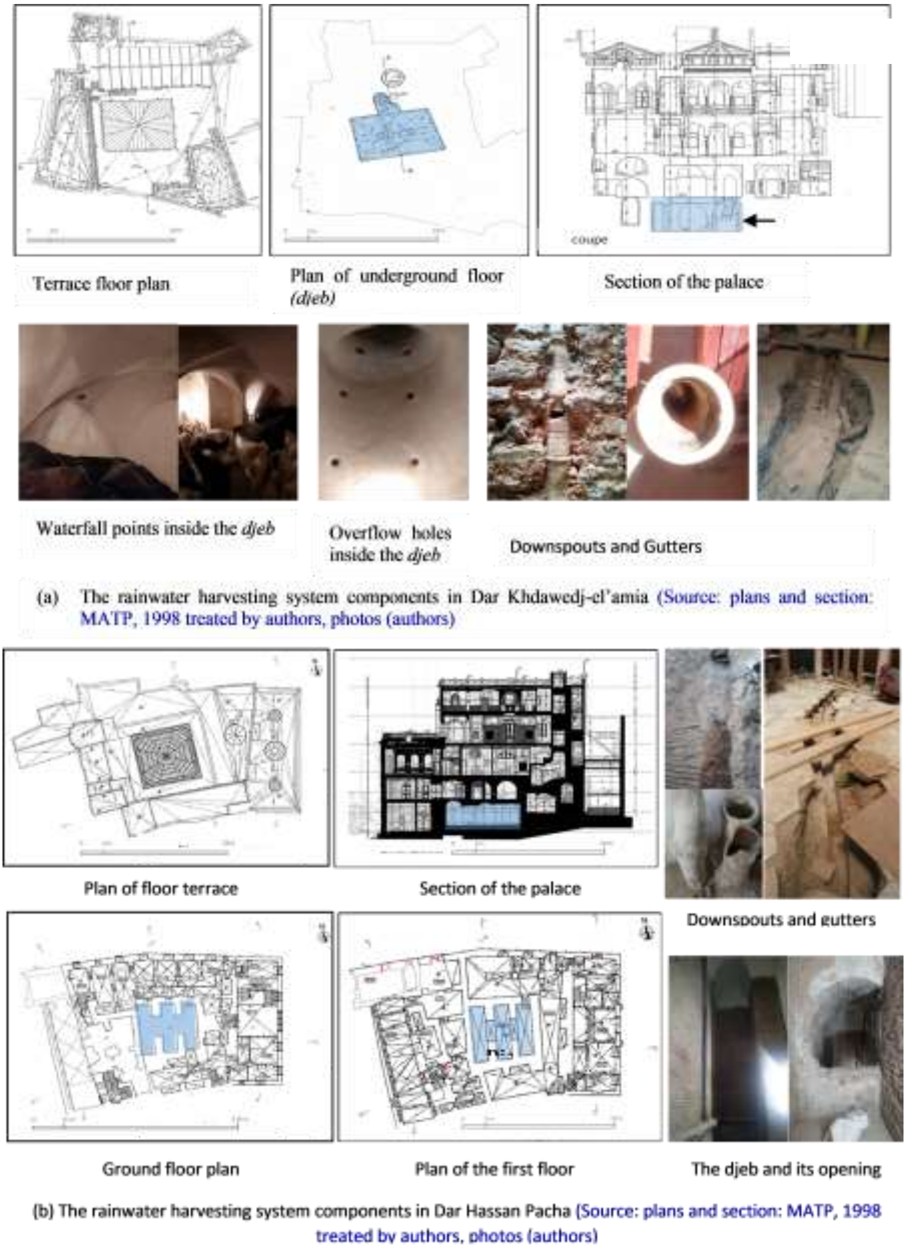


Fig. 3. Components of the system in both case studies.

The *Hassan Pacha* Palace underwent important transformations during the French occupation [36]. It was classified as a historical monument in 1982, but it remained in a derelict state until the launch of restoration work in 2016, which is still ongoing. These transformations touched the structure of the *Djeb* and its function.

Material and methods

Based on bibliographic and archival data and the surveys carried out during the restoration work, we collected all the data required on the rainwater harvesting system within the Algiers Ottoman houses.

For the architectural restitution of the system installation, our methodology included three-dimensional modeling using Revit: a software tool used to streamline the engineering design process, providing; design, model, and document-building systems in the context of a full-building information model, including architectural volume and technical installations. In this context, the model in this study shows the architectural volume of the houses, including the technical design of their hydraulic systems.

In addition, to verify the system's performance and reliability, we adopt mathematical modeling in our methodology, which consists of the system pre-sizing using rainfall measurements. This allowed us to examine the function of the rainwater harvesting system with the European standard of calculation, NBN EN 12056-3, which was published in 2000, following an update of the Belgian standard NBN 306, originally published in 1955 as a code of good practice in rainwater management within buildings [37]. Algeria, in its turn, has adopted this standard, which is mentioned in the National Regulatory Technical Documents 2010. The current standard can be applied to rainwater evacuation installations within dwellings by gravity. It defines the method of hydraulic calculation for rainwater capacity and the demands of the wet pipe network. It is applied to all materials used in the rainwater evacuation system, regardless of the fabrication method.

The formula of calculation used in the performance verification of this RWH system installation includes

- the volume of rainwater recovered over the year;
- the volume of rainwater at the *Djeb* overflow level;
- the number and diameter of downspouts.

In the field of hydraulics, the volume of rainwater recovered over the year can be written as follows:

$$V_R = R_{An} \times C_r \times A_r \qquad (1)$$

where:

V_R : Volume of rainwater recovered over the year (m^3/year)

R_{An} : Annual rainfall (mm)

C_r : The runoff coefficient is a factor that affects the amount of rainwater collected for a flat roof C_r =0.6.

A_r : Rainwater catchment area (roof area) (m^2)

On the other hand, the volume of rainwater at the *Djeb* overflow level can be written as:

$$V_{Rd} = A_d \times H_d \qquad (2)$$

where:

V_{Rd} : The volume of rainwater at the *Djeb* overflow level (m^3)

A_d : surface area of *Djeb* (m^2)

H_h : height of overflow outlets (m)

The number of downspouts can be written as follows:

$$D_N = \left(A_t \times \text{Cos}\ \alpha\right) / A_p \qquad (3)$$

where:

D_N : The number of downspouts

A_t : The surface of the terrace

A_p : The roof plan area served to match the diameter of the downspout.

α : The angle of the slope of the roof escape

Note: the plan area of the roof served to match the downspout is determined by the standard NBN EN 12056-3 in the diagram (Fig. 4).

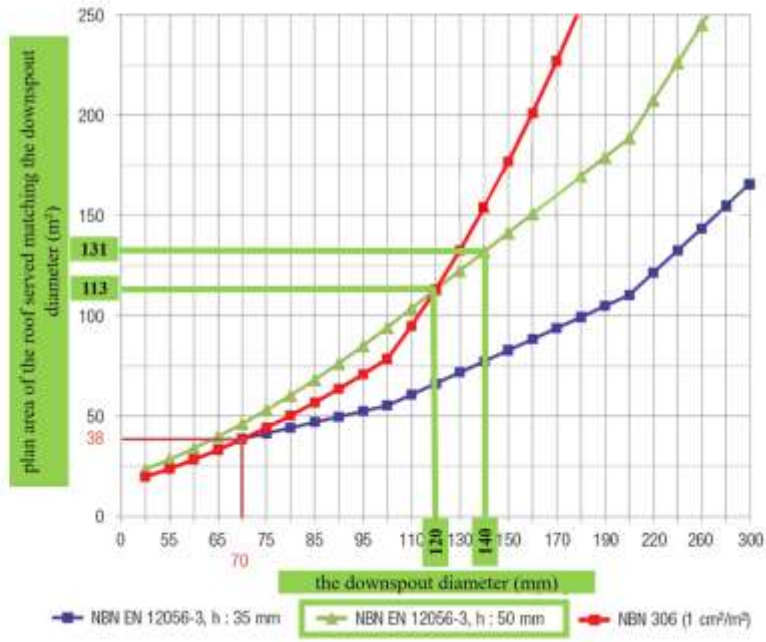


Fig. 4. Diameter of the downspouts /roof plan surface according to the European standard NBN EN 12056-3.

The system's reliability in this study was determined by comparing the data in the system on the site and the results of the calculations (Fig. 5).

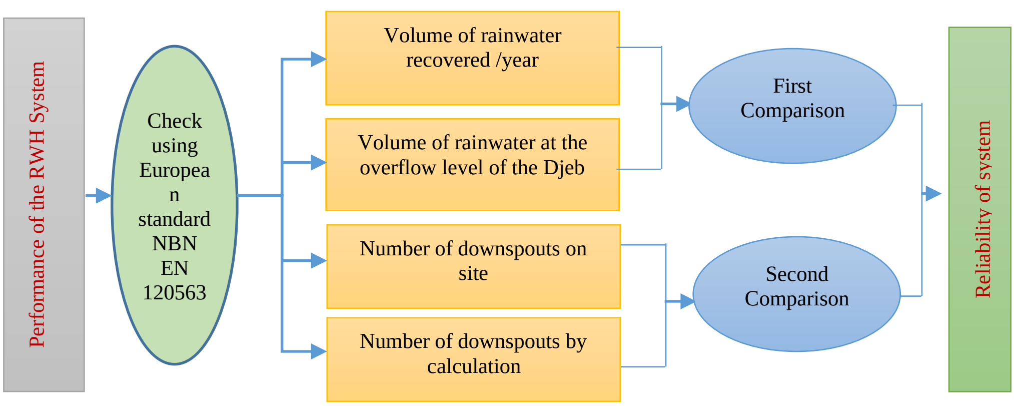


Fig. 5. Methodology flow chart.

For the rainfall data, we have chosen the oldest Monitoring Station of near Algiers, which dates from 1889, to be closer to the old rainfall data of the Ottoman period in Algiers

Results and discussion

Restitution of the original system installation

The first part of the result shows the RWH system design with its original installation and components. It is based on the restitution test, which consists of a 3D modeling of the system embedded inside the building, using the REVIT SOFTWARE**.**

From a restitution test, it became clear that the rainwater harvesting system at both *Khdawedj-El'Amia* and *Hassan-Pacha* palaces is made up of several correlated elements such as the rainwater catchment area in the roof, the cistern (*Djeb*), the downspouts and the gutters, and the well or a sewage system (Fig. 6).

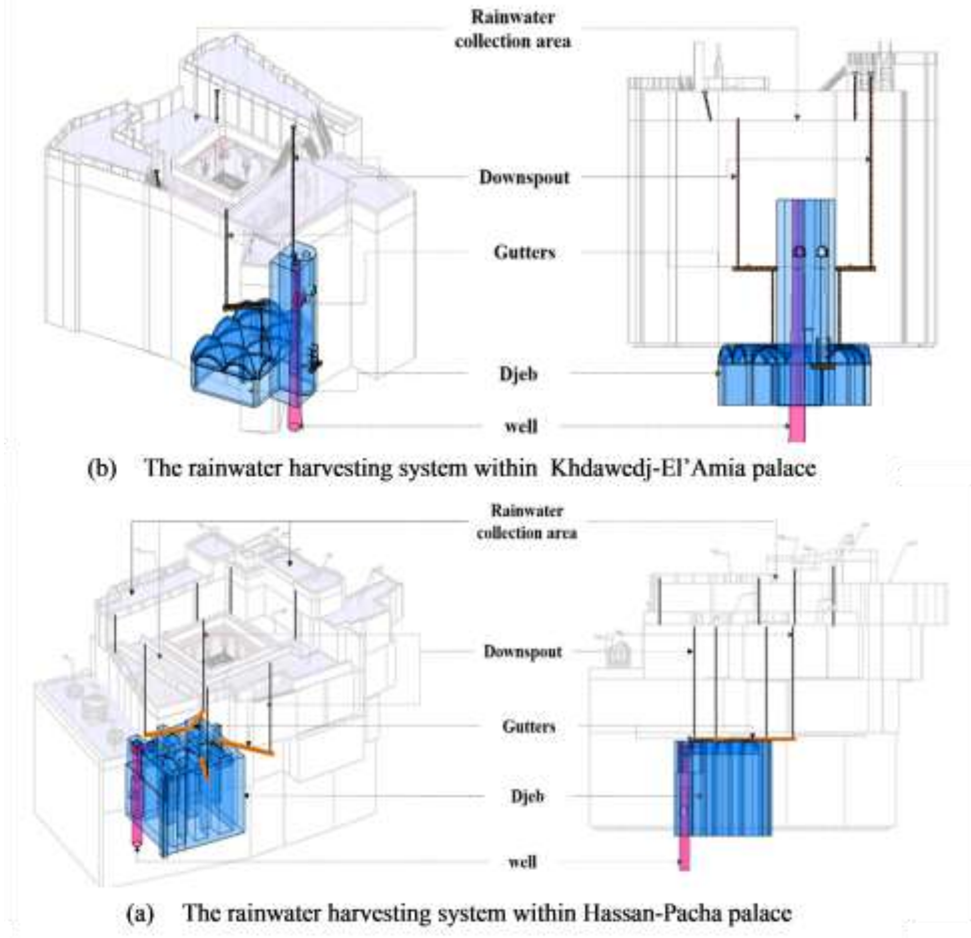


Fig. 6. Restitution design of rainwater harvesting systems installations within buildings.

Rainwater Catchment Area

The rainwater catchment area, present as the roof area of the palace, is estimated to be 315.42m^2 in the palace of *Khdawedj-El'Amia.* And, by 595.59m^2 in the palace of *Hassan-Pacha*, in the two cases, the rainwater catchment area encompasses the whole of the original terraced area, which was built during the Ottoman period. It corresponds to the raised parts of the terraces around the patio. Currently, the roof area is larger because of the extension of the building in the colonial occupation and the covering of the patio in both case studies (Tables 1 and 2).

Table 1. Component details of the RWH system in the case of the khdawedj-El'Amia palace

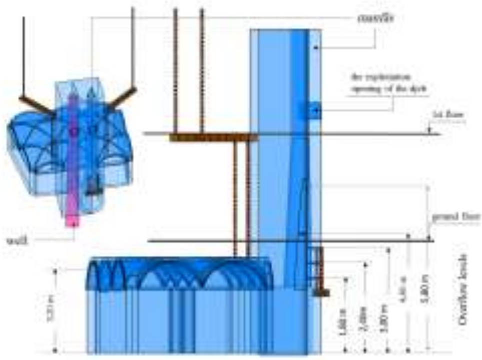
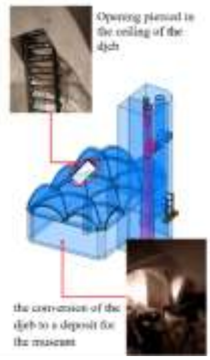
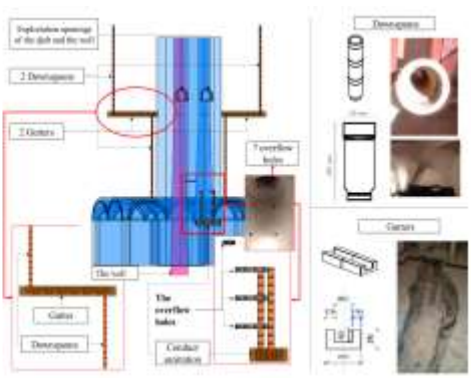
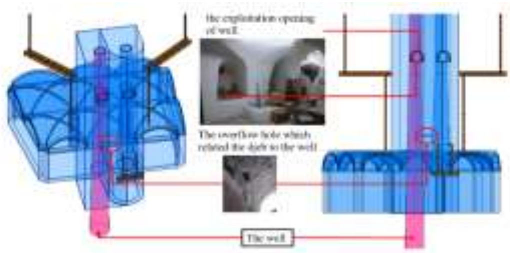
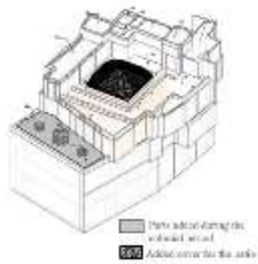
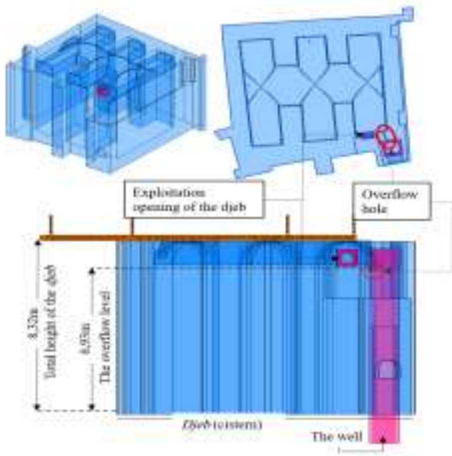
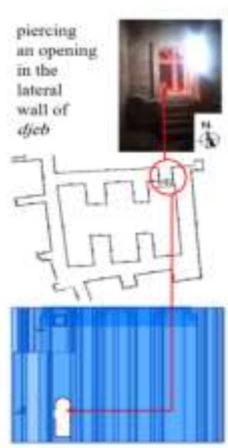
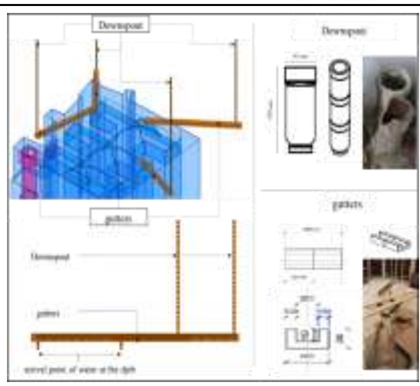
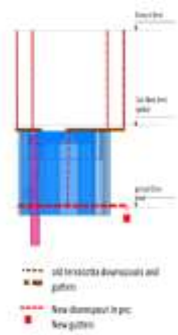
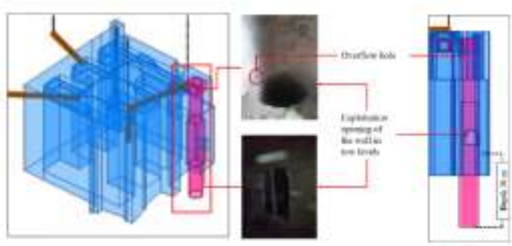
Components of rainwater system	**Original state**	**Current state (Transformation)**
Rainwater catchment area		
The cistern (*Djeb*)		
Downspouts and gutters		
Well		

Table 2. Details of components of the RWH system in the case of the Hassan-Pacha palace

Components	Original state	Current state (Transformation)
Rainwater catchment area		
The cistern (*Djeb*)		
Downspouts and gutters		
Well		

The cistern (Djeb)

In the palace of *Khdawedj El-Amia*, the *Djeb* was built in the basement, at a depth of -3.43m, over an area of 50m^2, and at the height of 3.20 m, giving it a volume of 160m^3. It consists of a massive structure of very thick masonry walls made of brick and stone (0.50 m to 0.80 m) and a terracotta masonry roof, which is made up of a series of six ribbed vaults, supported on all sides by thick walls, with two pillars in the center. The *Djeb* is linked to a vertical canal (*Manfâs*) with an opening allowing the *Djeb* to be used from the first floor. It also has in the wall of this canal 8 overflow holes arranged in five rows; the first three rows have two holes on each row, making a total of six in all, placed 60 cm one above the other, with the first pair 1.80m from the floor of the *Djeb*. These evacuate the surplus water from the interior of the *Djeb* to the sewerage system, while the 4th row at 4.80m height and th 5th at 5.80m height contains the 7th and 8th holes, respectively which evacuate the surplus water at this level from the *Djeb* to the well. Currently, the *Djeb* does not function, it has become a museum warehouse, and an opening was cut into its roof, allowing direct access to its interior (Table 1).

In the case of *Hassan-Pacha* palace, the *Djeb* was built on the ground floor, at a depth of -0.82m, over an area of 52.53m^2, and at the height of 8.00 m, giving it an immense volume of 445.29m^3. It consists of a massive structure of very thick masonry walls made from brick and stone (1 m to 1.50 m) and a roof with three ribbed vaults, placed lengthwise and built of brick. Its opening allows it to be used from the first floor. This is placed sideways in the wall, at a higher level than the overflow hole, which is situated 6.93 m from the floor of the *Djeb*. The actual state of the *Djeb* has exposed a second opening, subsequently cut into the wall, to allow it to be used from the ground floor. This has seriously undermined its utility, making water storage impossible and thus relegating it to some other purpose (Table 2).

Downspouts and Gutters

In the palace of *Khdawedj El-Amia*, the rainwater catchment area in the roof is linked to the *Djeb* by two vertical downspouts, which join two horizontal gutters embedded into the patio's floor on the first floor. The vaulted roof of the *Djeb* is crossed by two downspouts allowing the water from the two gutters on the first floor to the volume of the *Djeb* in the basement; they represent the inflow points inside the *Djeb*. The downspouts and the overflow holes are composed of cylindrical terracotta tips 120 mm in diameter, fitted one inside the other, ensuring the general flow of the water vertically. The gutters direct water to flow horizontally (Table 1).

In the case of *Hassan-Pacha Palace*, the rainwater catchment area on the roof is linked to the *Djeb* using four vertical downspouts, 140 mm in diameter, and four horizontal gutters, placed above the roof of the *Djeb* and embedded in the ground of the patio. Three points cross the Djeb falls, with the same thickness as the vaults, formed by interlocking cylindrical elements made of baked earth, allowing rainwater to flow towards the inside of the *Djeb* (Table 2).

Today, this installation has been abandoned in both cases due to the deterioration of its earthen drainage, preventing a direct connection between the rainwater catchment area in the roof and the *Djeb*, thus provoking a system malfunction. Rainwater is, at present, redirected towards the public sewerage system using new installations in PVC.

The Well

In the *Khdawedj El-Amia* palace, the well is connected to the *Djeb* by the overflow hole located in the wall, which separates the well from the *Djeb* at a height of 4.8 m from the tank floor. In the case of a surplus at this level, this overflow hole ensures the passage of water from the *Djeb* into the well, ensuring the safety of the whole system. At the same time, its opening exploitation is located in the laundry room (*bit es'saboun*) adjacent to the *Djeb* exploitation opening (Table 1).

In the case of *Hassan-Pacha* palace, the well is connected to the *Djeb* by an overflow hole, which is situated in the wall, which separates the well from the *Djeb*, at the height of 7 m from the floor of the *Djeb*. In the event of a surplus, this overflow hole ensures the passage of water from the *Djeb* to the well, ensuring the safety of its hydraulic elements (Table 2).

Ultimately, the two cases of study present the installation of the rainwater harvesting system connected to a well within the mansions and palaces of Ottoman Algiers, both using the same installation logic. The difference between the two installations lies in the dimension and position of *Djeb*, situated on the ground floor in the case of the Hassan-Pacha palace, and in the basement, in the case of the Khdawedj-El'Amia palace, which determines the location of both the exploitation openings and the overflow holes and its number. In Hassan-Pacha palace, the well was an integral part of the system and received surplus water from the *Djeb*. However, in Khdawedj-El Amia palace, the *Djeb* evacuated its overflow to the traditional sewerage network for the first time and then to the well; indeed, the well and the sewerage network present an extension of the rainwater harvesting system within the Ottoman houses.

Both systems show that the correlation between the components of the system affects its performance. The malfunction of the system was caused not only by the transformations within the *Djeb* but also by those related to the pipes, bringing water from the terrace to the same *Djeb*, ensuring its correlation.

Performance of the RWH system using pre-sizing modeling:

The second part of the result aimed at verifying the studied system's reliability and performance. Our work is based on calculating three parameters plus comparisons, as mentioned in the methodology part (Fig. 5).

Cistern capacity/rainwater

The first application compares the cistern volume at the overflow level with the volume of rainwater recovered over a year; using the formula number (1) and (2) mentioned in the methodology, we have the result in Table 3.

Table 3. Result of the RWH system in our site

Place	$R_{An}(mm)$	C_r	$A_r(m^2)$	$V_R(m^3)$	$V_d(m^3)$	$A_d(m^2)$	$H_h(m)$	$V_{Rd}(m^3)$
Khdawedj-El'Amia	1041.8	0.6	315.42	**197.16**	160	50	3	**90**
Hassan-Pacha	1041.8	0.6	595.59	**372.52**	445.29	53.52	6.93	**370.89**

Table 3 shows that the amount of rainwater collected over a year for *Khdawedj-El'Amia* was more than the volume of the *Djeb* at the first overflow level. This can be explained by the presence of eight overflow holes, arranged in five rows, six of them related to the sewerage network and the 7^{th} and 8^{th} one related to the well (Table 1), which ensure the safety of the *Djeb* in the case of a surplus amount of water in different levels.

As for *Hassan-Pacha*, the result shows that the volume of rainwater recovered over a year is close to the volume of the *Djeb* overflow level. We know that the *Djeb* contains only one overflow hole. This shows that the *Djeb* capacity is compatible with the surface value of the rainwater catchment area and the rainfall. This explains that the *Djeb* can store all the rainwater recovered in a year.

First comparison

By comparing the installation and performance of the systems in both case studies, we observed that their installations, and the position of the *Djeb* within the palace, depending on parameters derived from actual data, such as the dimensions of the palace, the shape of the land on which the edifice was built, as well as by the steep terrain. In this context, we cannot ensure the construction of the *Djeb* with a size that is compatible with the quantity of rainwater recovered, as in the case of *Hassan-Pasha* palace.

Therefore, we notice that in the event of incompatibility between the volume of the *Djeb* and the volume of the rainwater recovered, the *Djeb* must be equipped with a sufficient number of overflow holes to ensure its safety by evacuation of its surplus at different levels as in the case of khdawedj-El'Amia palace.

In terms of consumption, the compatibility between the volume of the *Djeb* at the level of overflow and the volume of the rainwater recovered a whole year confirms that this water was used only in case of need, as they store the water for a long time to be consumed in the drought period. In addition to the presence of the well as the main water source within the palace, this directly impacted the use of the *Djeb.* While in the case of incompatibility, the use of the rainwater collected in the *Djeb* was essential because it helped to maintain a balance between the water stored in the Djeb and the quantity consumed.

Our studies show that the well and the *Djeb,* which are adjacent, are connected by an overflow hole, which allows for the evacuation of surplus water from the *Djeb* towards the well. This link between the well and the *Djeb* can be explained from a hydrological point of view that it serves a dual purpose as a groundwater recharge in this urban area, simultaneously raising the water level in the well. That is why the water level in the well is higher in winter than in summer, wherein the water has a saltier taste. In contrast, the connection between the *Djeb* and the sewerage network by additional overflow holes can be explained that the volume of the well cannot accommodate all the quantity of the *Djeb* surplus.

Rainwater catchment surface in the roof / Number of downspouts

The second application compares the number of downspouts found in the result calculation and in the site and in both case studies using formula number (3) as mentioned in the methods (Table 4).

Table 4. Number of downspouts in both case studies

Place	A_t	α	Cos(α)	A_p	D_N	Dounspots number on site
Khdawedj-El'amia	315.42	1.5	0.99	113	**2**	**2**
Hassan-Pacha	595.59	1.5	0.99	131	**4**	**4**

Table 4 shows that the calculation result of the downspouts number corresponds with the number observed at the site used in the first part of the restitution results in both case studies (Tables 1 and 2).

Second comparison

The downspouts' size and number must be compatible with the surface value of the rainwater catchment area in the roof to ensure the evacuation of all the rainwater collected in the roof to the *Djeb*. In the *Hassan-Pacha* palace, where the terrace covers an area of 595.95 m^2, has four (04) downspouts, while the *Khdawedj-El'Amia* palace, whose terrace is 315.42m^2, has only two (02) downspouts.

The dimensional compatibility between the rainwater areas, the number of downspouts, and their diameter confirm that the performance of the rainwater harvesting system depends on a good correlation between the installations of its components, which is ensured by the downspouts and gutters.

Reliability of the system

Indeed, the restitution of the original installation of the RWH system and verifying its performance using current standards confirms its reliability and, consequently, the possibility of putting it in function today.

However, putting the system in function today requires some specialized expertise, such as:

- Verify the structural capacity of the cistern (*Djeb*).
- Cleaning and disinfection of the cistern (*Djeb*), downspouts, and gutters.

- The use of materials recommended by today's standards must be compatible with historical buildings.
- Determine the intended use of this collected water.
- Periodic control, cleaning, and maintenance.

As the implementation of the current system requires the integration of new operating methods where the rainwater collection system must be equipped:

- A filtration system or purification system that varies depending on the use and can range from simple screening to retain the leaves to filtration downstream of the tank,
- A regulation system: level indicator, overflow relay, non-return valve.
- A water redistribution system with pressurization (using pumps), identified piping network, special taps, etc.

The RWH system presents the most suitable way for rainwater management, and the use of this water resource today is strongly encouraged as a sustainable and ecological approach to the problem of water scarcity today.

Conclusion

Rainwater management in Ottoman Algiers and its exploitation is ensured by the construction of storage rainwater cisterns (*Djeb*) inside residential buildings, which were implanted on sloping terrain and conceived in such a way as to allow for the recovery of rainwater from flat roofs linked by terracotta downspouts to the *Djeb*. This installation represented an ad-hoc system, which could be found in almost every house, ensuring its occupant's self-sufficiency in water, reinforced by the presence of a well.

Most of these installations are no longer in operation. They are in a dilapidated state, caused, for the most part, by the anarchic transformations made to them during the colonial and post-colonial periods.

Our restitution of the original state of the rainwater harvesting systems (RWH-system) confirms that its performance depends on a good correlation between all its components. It is clear, for example, that the water supply within the *Djeb* within the house depends on its contact with the rainwater catchment area on the roof through a series of vertical downspouts and horizontal gutters. As for the evacuation of its overflow, it is ensured by overflow holes. This installation allows safe storage and exploitation of rainwater through a well-thought-out integration of the *Djeb* within its context, taking into account its location within the house and the topography of the terrain, as well as the dimensions of the house and its typology.

As a general rule, we have shown that the capacity of the *Djeb* should be compatible with the amount of rainwater recovered from the terrace over a whole year, as in the case of *Hassan-Pacha* Palace. Otherwise, the safety of the *Djeb* is ensured by the evacuation of surplus water by a sufficient number of overflow holes, which are connected to the well, to the sewerage system, or to both, to receive the *Djeb* surplus, as in the case of *Khdawedj-El'Amia* palace. This has led us to conclude that both the well and the sewerage network are integral parts of the rainwater harvesting system within the Ottoman Algiers houses.

Rainwater management, using a *Djeb*, in palatial and residential buildings in Ottoman Algiers, consists of harvesting, supply, and evacuation, where the cistern allows for the exploitation of the water stored inside and its evacuation in the case of a surplus amount.

Today, in light of the old built environment deterioration, water offers a severe threat. It has been recommended that more attention be given to rainwater management in the old Ottoman Algiers.

Consequently, this restitution of the rainwater harvesting systems, presented in our study, offers an essential understanding of the nature of its transformations and an assessment of its degree of degradation. While verifying the system's performance in relation to present-day standards allows for foreseeing a possible resumption of its use.

Based on this research, it is possible to envisage other research perspectives, which can be related to the restoration and rehabilitation of the system that manages rainwater within the Ottoman houses in Algiers. To counter and limit their transformations, but also to regulate their use.

Acknowledgments

In particular, we would like to mention the institutions that contributed to this study: the Department of Public Facilities of Algiers, which gave us access to the ongoing restoration work inside the Hassan-Pasha Palace. OGEBC archive annex provided us with archival documents related to this research. ATP museum currently occupies the Khdawedj-El'Amia palace, which has accompanied us with any on-site investigation within the palace and has provided us with all documents concerning the palace from its part.

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Received: January 31, 2022
Accepted: April 02, 2023