

## ANALYSE AND REPAIR OF STONE MASONRY BUILDING IN MEDITERRANEAN AREAS: CASE OF POUILLON'S HOUSING ESTATES IN ALGIERS, ALGERIA

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### Abstract

*Built in 1954 on the heights of the city of Algiers, the dwellings of Diar El Mahçoul are one of the masterpieces designed by the French architect Fernand Pouillon in Algeria. These buildings are entirely made of stone and with innovative techniques. They are known not only for their historical value, but also for their architectural and symbolic importance. Given the value of this heritage to the city of Algiers, its preservation is a priority. This article presents the rehabilitation process of the stone masonry tower of the Diar El Mahçoul housing estate. This research is based in situ observation of the mechanism of deterioration of the stone walls. The objective through this study is firstly to determine the state of conservation of the stone after 65 years of its construction using the RehabiMed method, secondly to list the mechanisms of deterioration and degradation of different materials as structural and ornamental elements are, and finally to present the rehabilitation method adopted for the sandblasting of the stone walls. As a conclusion to this study, the conservation of Pouillon's heritage is important because it allows us to pass it on to future generations.*

**Keywords:** Stone masonry; Architectural heritage; Fernand Pouillon; Mediterranean areas; RehabiMed method

### Introduction

Masonry constructions in earlier times were generally designed on the basis of building rules and traditional knowledge and skills. An example of this is the large ensembles of Diar El Mahçoul (Fig.1), designed by the French architect Fernand Pouillon in 1954 [1]. Pouillon is a practical builder who marked the 1950s due to the design of several architectural projects. These buildings are now considered as a remarkable heritage, worthy of being recognized for its exceptional value.

The particularity of the architecture of Pouillon is the use of fontvieille stone imported from Marseille to Algiers especially for the construction of three housing estates in the city of Algiers: Diar Es Saada with 735 apartments, Diar El Mahçoul with 1550 apartments and Climat de France with 3500 apartments. In total, 5785 housings designed using construction methods invented by Pouillon [2].

The starting point for Pouillon is the rationalization of the building. He is looking for economical construction systems that guarantee the greatest possible simplicity of installation, preferably structures with thick load-bearing walls, stones or bricks, without reinforcement. This rational architecture is inspired by a strong image borrowed from a "Mediterranean" vein;

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whether classical, French, Spanish, Portuguese, Moorish — explicit or metaphorical, but always in the same constant and austere writing [3-6].

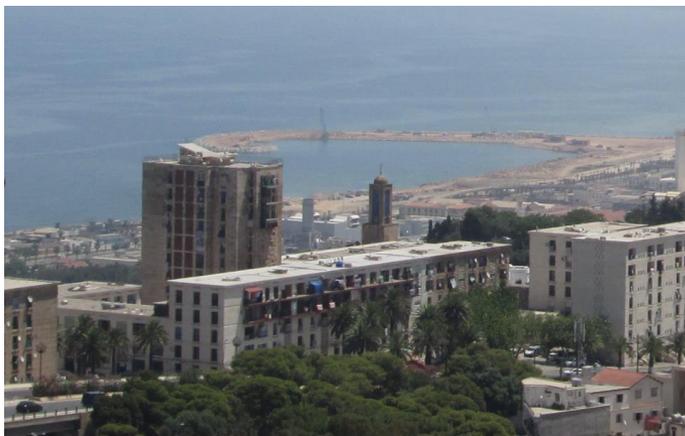


Fig. 1. The city Diar El Mahçoul

**Methods**

There are several simplified guides in the literature proposed for the analysis and diagnosis of masonry buildings. Methods that aim to provide results that can be used to preserve heritage buildings because of their intrinsic values.

This study is in line with research work on the structural analysis of Pouillon's works. Indeed, a study has already been carried out by the Rehabimed method [7].

RehabiMed (Fig. 2) is a method for the rehabilitation of traditional mediterranean architecture. A good diagnosis will help to target and prioritize the interventions.

This study was carried out using the following methodology (Fig. 2).

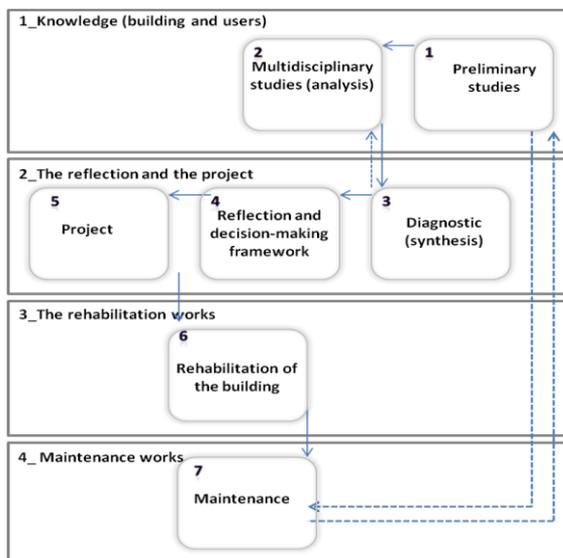


Fig. 2. The flowchart of the Rehabimed method [4]

## Application of the method

### *Presentation of the case study: the Diar El Mahçoul tower*

For the case study was finally chosen for building J of the city Diar El Mahçoul. This is a tower (Fig. 3) with eleven-storey construction (R+10), designed entirely in solid stone masonry.

The city Diar El Mahçoul is formerly called the city of promise kept (cité de la promesse tenue). It was made in 1954 by Pouillon. This large complex includes 1550 dwellings in 38 buildings of five to six levels and a tower of 11 levels, 38 shops, and a school group of 25 classrooms, a garage for 350 cars, a post office, sports fields and a covered market.

According to Pouillon, this tower is designed to be a landmark for the entire neighborhood, in the market square.

The tower of Diar El Mahçoul construction site began on June 17, 1954 and was completed on August 14, 1954. Thus, the realization of the city lasted 58 days [8].



Fig. 3. The views of Diar El Mahçoul tower

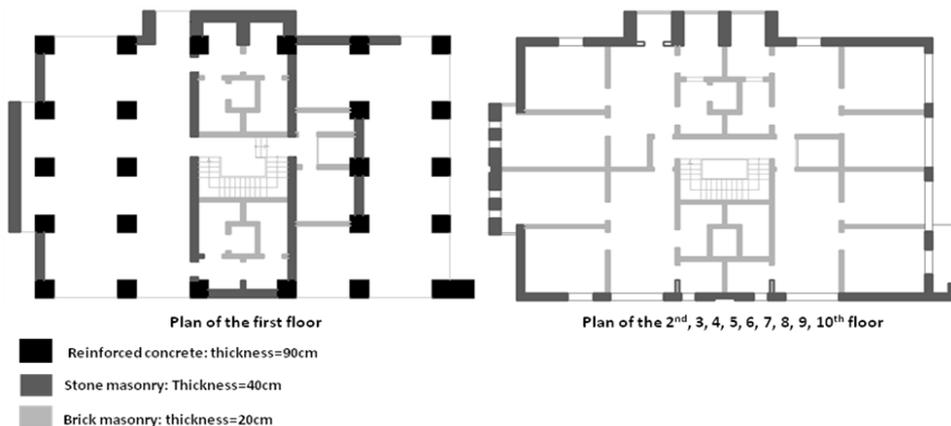


Fig. 4. Representation of deferent walls thickness

### *Constructive system of the tower*

The structure of the tower is built using contemporary techniques and traditional materials (Fig.4):

- the foundations: pebble concrete or reinforced concrete footing;
- the walls: white dressed stone and a brick counterpart reserving an air space to isolate the apartment from heat and cold [1];
- the walls: in tubular bricks of 20cm finished thickness, mounted in cement mortar;
- cross-ribbed reinforced concrete slab floors with soundproofing, tiles and plaster-finished ceilings.

#### ***Synthesis of structural condition assessment using the Rehabimed method***

Before starting the more in-depth diagnosis on the tower's constituent stone, it is necessary to collect as much data as possible and to examine the state of conservation of the structure. For this purpose, the analysis was started with the Rehabimed method [7]. As summarized in the following flowchart, the result of the diagnosis made is summarized as follows:

- deterioration of the concrete, revealing the reinforcement of the floors at the level of the balconies;
- alteration of building stones: loss of material (perforation, pitting, disintegration and erosion), color change (crusts and crushing) and biological colonization (lichens and mosses) [9-12];
- the crumbling of ceramic decorations, which characterize many buildings;
- loss of material (coating) due to infiltration of rainwater;
- the facades of the buildings appear dull, which gives off a unaesthetic character and offers visitors an unpleasant view.

However, apart from significant damage to non-structural elements, cracks or deterioration in the walls were observed that would indicate vulnerability to seismic risk [13].

#### ***The characteristics of the stone***

The stone used in the realization of the great ensembles of Diar El Mahçoul is extracted from the quarries of Fontvieille, located in the Bouches-du-Rhône. Fontvieille stone is a white limestone with blond reflections. It is also called "Pierre de Provence" and was widely used by the architect Fernand Pouillon in the 1950s in France and Algeria.

This stone has been used in the realization of historical buildings such as, the Arena of Arles and the Abbey of Montmajour. The characteristics are the following [14]:

- type of stone: limestone
- commercial name: Fontvieille
- dominant color: white with blond highlights
- dominant aspect: medium to fine grained compact
- mass volume: 2030 to 2070kg/m<sup>3</sup>
- porosity: 23.1 to 24.6%.
- flexural strength: 4.9 to 5.6MPa
- abrasion: 39.5mm
- capillarity C1: 107.3g/m<sup>2</sup>
- capillarity C2: 103.3g/m<sup>2</sup>
- compression: 9MPa
- frost resistance: 16 cycles

#### ***Damage analysis of the stone***

As shows in Figure 5, there is revealed a few pathologies, which are related to the lack of periodically maintenance and the environment (proximity to the sea).

#### ***Factors affecting degradation processes of the tower***

The most important factors (Fig. 6) affecting degradation of the tower is related to [9]: environment; materials; design and maintenance.

		
<b>Features induced by material loss</b>	<b>Discoloration &amp; deposit</b>	<b>Biological colonization</b>
Erosion Pitting Perforation	Crust Deposit Discolouration Subflorescence	Lichen Moss

Fig. 5. The different forms of degradation and apparent pathologies identified

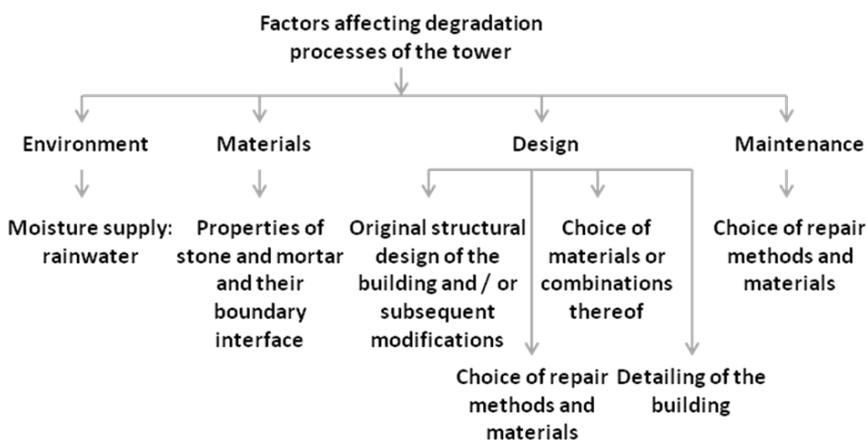


Fig. 6. Important factors for damaging of the tower [15]

Principal factors related to the environment are the moisture supply: the tower of Diar El Mahçoul is located on the heights of the municipality of El Madania in Algiers, a few meters from the Mediterranean Sea. Indeed, among the buildings of the allotments of Diar El Mahçoul, the frontages of the buildings facing the sea are the most exposed to deteriorations. Add to this the Mediterranean climate and rainwater, a factor which is not negligible.

Principal material factors are the properties of the stone and mortar and their boundary interface: the limestone used in the construction of the tower comes from France quarries. The main characteristic of this material is its high permeability due to its high porosity.

The design factors are the original structural design of the building and/or subsequent modifications; the rehabilitation of the tower stone in 1981 has weakened its surface, which has led to loss of material at the walls and accelerated the natural degradation of the stone; choice of materials; detailing of the building (especially water shedding details like gutters, downpipes, window sills, copings, flashings, roof overhangs); and respectively the choice of repair methods and materials (treatments, cleaning operations).

Factors related to maintenance are the prompt repair and lack of maintenance: the housing estates of Diar El Mahçoul suffer from lack of periodically maintenance. Since its completion the tower stone has been rehabilitated twice: the first in 1981 and the second recently in 2018.

The environmental factors, combined with material factors, exert a major influence on the development of degradation processes.

### ***History of the tower's rehabilitation work since its construction in 1954: restoration and repair***

Since its completion, the Diar El Mahçoul city has undergone two rehabilitation interventions since 1981 and 2018 (Fig. 7), which consists of renovating the façades, in order to extend its lifespan [16].

Stone façades are subject to their own pathologies. There is a wide range of interventions available to ensure the conservation of this material. In this case, they opted for mechanical cleaning by sandblasting.



**Fig. 7.** Rehabilitation work on the Diar El Mahçoul tower in 2018

### ***The process of mechanical stone cleaning***

Stone cleaning methods have diversified based on different principles of action [17]: washing with water (nebulisation and projection of water under low pressure, cataplasms); mechanical cleaning (sandblasting or fine gumming and fine hydrosanding); chemical cleaning (surfactants, complexing agents).

After an in-depth study of the mechanisms of deterioration of the tower stone, the method of mechanical cleaning (sandblasting) was selected for the conservation of the stone. Sandblasting is a mechanical method particularly adapted to remove surface deposits. The advantages of fine sanding are the following: no risk of water soaking, so it can be used in winter; no risk of water infiltration, efflorescence or stains; can be used locally.

Its disadvantages and limitations are as follows:

- the nuisances generated and the dust: sanding requires the wearing of a helmet against dust suction for the operator and a shelter and special protection equipment;
- limiting the diffusion of particles into the environment;
- low efficacy on plant organisms (lichen, mosses etc.), the high risk of damage if the handler is not well done;
- dust stuck on the stone, results in white shades and possible residual pollutants.
- Sandblasting will be performed in a weighted rhythm but no very fast. In the event of damage, any blasting intervention will be stopped immediately.

## **Conclusion**

The buildings belonging to the colonial period constitute the main component of large Algerian cities and occupy a large part of our real estate assets. Fernand Pouillon's large ensembles stand out from other buildings by the materials and techniques used by this architect, hence the need to preserve this architectural heritage.

In this research work, an adapted methodology for analysis and repair of the Diar El Mahçoul was presented and followed in order to carry out a seismic evaluation of the conservation state.

As a conclusion, it can retain from this study the following:

- the causes of degradation are very varied. It is only once the diagnosis has been established, after that, the causes of degradation are identified and the state of conservation of the stone is recognized. Only in these steps it becomes possible to envisage one or more interventions.
- mechanical cleaning by sandblasting may be the easiest, quickest and cheapest solution, but these disadvantages are not negligible. The cheapest solution is not always the most effective. In fact, too much cleaning can give the stone an unsightly appearance and accelerate or cause damage, especially when the building is located in a damp environment.
- in order to avoid heavy interventions due to very important degradations, it is preferable to carry out maintenance on a regular basis using the appropriate tools for the conservation of the material.

This paper propose for future work another more in-depth study on the impact of mechanical cleaning (sandblasting) of the stone from Diar El Mahçoul Tower and on its durability.

## References

- [1] F. Pouillon, **Mémoires d'un architecte**, Éditions du Seuil, Paris, ISBN 978-2-02-001114-3, 1968.
- [2] C. Sayen, **L'Architecture par Fernand Pouillon**, Éditions Transversales, Toulouse, ISBN 978-2-9520365-4-2, 2014.
- [3] M.M. Abdelmegeed, E. Badogiannis, G. Kotsovos, E. Vougioukas, *Structural Damage Assessment Of Historic Traditional Masonry Buildings: A Case Study*, **International Journal of Conservation Science**, **6**(2), 2015, pp. 165-176.
- [4] A. Murano, J. Ortega, G. Vasconcelos, H. Rodrigues, *Influence of traditional earthquake-resistant techniques on the out-of-plane behaviour of stone masonry walls: Experimental and numerical assessment*, **Engineering Structures**, **201**, **2019**, Article Number: 109815. DOI: 10.1016/j.engstruct.2019.109815.
- [5] J.C. Domingues, T.M. Ferreira, J. Negrão, R. Vicente, *The safeguarding and preservation of the Built Heritage in old urban centres: a reflection on traditional stone masonry buildings' structural rehabilitation*, **Conservar Património**, **29**, 2018, pp. 51-62. DOI: 10.14568/cp2017030
- [6] A. Loeckx, P. Vermeulen, **L'habitat moderne à Alger (1925-1975): étude et évaluation de cites et quartiers du patrimoine moderne en vue d'une rénovation urgente. Deuxième partie : 15 cités modernes à Alger présentation d'un échantillon**, Éditions Centre Post Graduat Etablissement Humains, Département Architecture Urbanisme et Aménagement du Territoire, Katholieke Universiteit Leuven, Heverlee, Belgique, 1988.
- [7] X. Casanovas, **Méthode RehabiMed. Architecture Traditionnelle Méditerranéenne. II. Réhabilitation Bâtiments**, Éditions Consortium RehabiMed, ISBN 84-87104-73-8, 2007. [https://issuu.com/asociacionrehabimed/docs/metodo\\_ii-batimentsfr](https://issuu.com/asociacionrehabimed/docs/metodo_ii-batimentsfr).
- [8] Y. Oukrif, *Approche structurelle comme facteur d'analyse du projet de Diar El Mahçoul de Fernand Pouillon*, **Master en Architecture**, École Polytechnique d'Architecture et d'Urbanisme, Octobre, 2016.
- [9] N. Touloum, A. Brara, *Diagnostic, morphologies et mécanismes d'altération des pierres de construction du parc bâti de l'algérois*, **Rencontres Universitaires de Génie Civil**, Vol. **XXIX**, Tlemcen, Algérie, 29 au 31 Mai 2011, pp. 193-202.

- <http://dspace.univ-tlemcen.dz/bitstream/112/532/1/Diagnostic-morphologies-et-mecanismes-dalteration-des-pierres-de-construction-du-parc-batide-lalgerois.pdf>.
- [10] O. Bergamo, G. Campione, C. Cucchiara, G. Russo, *Structural behavior of the old masonry bridge in the Gulf of Castellammare*, **Engineering Failure Analysis**, **62**, 2016, pp. 188-198. DOI: 10.1016/j.engfailanal.2016.02.007.
- [11] J. Garcia-Guinea, L. Recio-Vazquez, G. Almendros, D. Benavente, V. Correcher, A. Perez-Garcia, S. Sanchez-Moral, A. Fernandez-Cortes, *Petrophysical properties, composition and deterioration of the Calatorao biogenic stone: case of the sculptures masonry of the Valley of the Fallen (Madrid, Spain)*, **Environmental Earth Sciences**, **69**(5), 2013, pp. 1733-1750. DOI: 10.1007/s12665-012-2007-2.
- [12] B. Ratoi, V. Pelin, I. Sandu, M. Branzila, I.G. Sandu, *Hidden Message in Stone Masonry of Galata Monastery - Iasi City, Romania*, **International Journal of Conservation Science**, **9**(1), 2018, pp. 151-164.
- [13] L. Mohammadi, A. Abdessemed-Foufa, M. Cheikh Zouaoui, *Contribution to the seismic vulnerability assessment of Fernand Pouillon's housing estates in Algiers*, **VUREST 2018: The 1<sup>st</sup> International Conference on Vulnerability and Rehabilitation of Structures**, University of Sciences and Technology Houari Boumedienne USTHB, Algeria, 07-08 May 2018.  
[https://www.researchgate.net/publication/337196519\\_Contribution\\_A\\_L'evaluation\\_De\\_L\\_a\\_Vulnerabilite\\_Sismique\\_Des\\_Grands\\_Ensembles\\_De\\_Fernand\\_Pouillon\\_A\\_Alger](https://www.researchgate.net/publication/337196519_Contribution_A_L'evaluation_De_L_a_Vulnerabilite_Sismique_Des_Grands_Ensembles_De_Fernand_Pouillon_A_Alger).
- [14] \* \* \*, **Carrières de Provence, Pierre calcaire de provence**, Estrailades, Fontvieille, Pont de gard. Exploitation de carrières de pierre de taille.  
<https://www.carrieresdeprovence.com/details-la+Pierre+de+fontvieille-55.html>.
- [15] R.P.J. van Hees, L. Binda, I. Papayianni, E. Toumbakari, *Damage analysis as a step towards compatible repair mortars*, (chapter) **Characterisation of Old Mortars with Respect to Their Repair**, Rilem Publication, ISBN 9782912143563, France, 2007, pp. 105-150, <https://www.rilem.net/images/publis/rep028-007.pdf>.
- [16] A. Behloul, **Les grands ensembles urbains essai de réhabilitation. Etude de deux cas à Alger: cite Diar El Mahçoul (El-Madania) et 08 Mai 1954 (Bab-Ezzouar)**. Mémoire de Magister, University of Sciences and Technology Houari Boumedienne USTHB, Algeria, Alger, 2008.  
<http://repository.usthb.dz/bitstream/handle/123456789/8093/TH5345.pdf?sequence=3&isAllowed=y>.
- [17] \* \* \*, **Pierre Sud. Base de données sur les pierres du patrimoine historique et archéologique du sud de la France**, <https://www.brgm.fr/projet/pierresud-base-donnees-sur-pierres-patrimoine-historique-archeologique-sud-france>.

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Received: January, 17, 2020

Accepted: November 3, 2020