Conservation And Restoration Of Historic Stone And Plaster Of Kutubiyya Mosque (Morocco)

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Abstract:

The problem of preserving our built heritage is a cultural and scientific challenge of great and even strategic importance, given that many monuments in Morocco have suffered significant deterioration. Since the renovation of facade and interior plasters is among the most common tasks in restoration projects, it is important to study the composition of these stone and plasters to ensure the compatibility of the materials used and their proper interaction with the substrate.To this end, our work involves characterizing the stone and plaster from the enclosure of the Kutubiyya, as well as the materials used for the restoration of the wall, using mineralogical, chemical, and petrographic characterization methods such as X-ray diffraction, X-ray fluorescence, and petrographic analysis.The masonry stone is a marly limestone with characteristics typical of hard rocks, and the primary exterior plaster is made of lime and silty sand, with the addition of a percentage of gypsum to accelerate setting. X-ray diffraction analysis revealed the presence of the following crystalline phases in the original masonry stone of the historical Kutubiyya Mosque: calcite, clays, quartz, and dolomite. Meanwhile, X-ray fluorescence allowed the determination of the major elements in our plaster (namely SiO2, SO3, CaO, Al2O3, MgO, and Fe2O3). These results highlighted differences in the chemical composition of the original and restoration palsters, thereby influencing the quality and efficiency of the restoration of the Kutubiyya in Marrakech.

Keywords: Kutubiyya, stone, coating, restoration, physico-chemical analysis

Introduction

Marrakech is the largest of the thirty-one living historical cities (medinas) of Morocco; it has an intramural area of 640 ha (not including the gardens of Aguedal and Menara). In 1985, the medina of Marrakech was listed as a UNESCO World Heritage Site. Among the most important historical sites in the medina of Marrakech is the Kutubiyya Mosque, which is of great importance for the history and archaeology of Morocco.

In the aftermath of the fall of Marrakesh to the Almohads in 1147, several Almoravid religious buildings were completely or partially destroyed. The Almohad chronicler al-Baydaq reports that the caliph ʿAbd al-Muʾmin [1130-1163] ordered the demolition of the great mosque of ʿAlī Ibn Yūsuf and several other Almoravid mosques, simply because they were directed towards the east, and thus did not conform, according to him, to the proper orientation of the qibla [1]. It was out of the question for the Almohad power to use the Almoravid mosques, which were considered impure and defiled, particularly because they looked towards the east (tashrīq), which would be similar, according to the words of the Mahdī Ibn Tūmart (d. 1130), to the orientation of the Jews and certain non-Muslims [2].And, in order to ensure that the city was well purified, they also demanded that others be built. ʿAbd al-Muʾmin did not fail to follow this invitation, as he built a great mosque. This was the first Almohad mosque, now ruined, the remains of which were found as early as 1923 [3]. Archaeological excavations directed by Jacques Meunié, since 1947,

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have shown us that it was built on the annexes and perhaps a funerary enclosure of the palace of ʿAlī Ibn Yūsuf. The work had to be carried out in an expeditious manner and with materials that were readily available locally, adobe for the walls and bricks for the pillars and arches. Its north wall was built on the curtain wall of the fortress and royal residence of the Almoravids, 'Qaṣr al-Ḥajar', whose bastions had been razed and whose south wall was the north wall of the present-day Kutubiyya, the second mosque of its kind. This first Almohad mosque had a minaret for the construction of which one of the corner towers of the Almoravid fortress was thickened and raised. As for the present minaret (it is about 77 metres high), begun by ʿAbdal-Muʾmin and completed by the two caliphs Abū Yaʿqūb Yūsuf [1163-1184] and Abū YūsufYaʿqūb [1184-1199], it was located between the two mosques which, at one time, were one [4].

If Henri Basset and Henri Terrasse, then archaeological excavations have proved that the first Almohad mosque and the present Kutubiyya could only be the work of the CaliphʿAbd al-Muʾmin, who reigned from 1147 to 1163, and while it is clear that the first Almohad mosque was built immediately after the capture of Marrakesh in 1147 and that it received the Qur'an from Uthman at the end of 1157, we had no such information about the Kutubiyya mosque [5].

The two authors of the Istibṣār state that ʿAbd al-Muʾmin "constructed there a greatcongregational mosque, which he then enlarged with one similar to it, towards the qibla wherethe palace once was, and between them was raised the most grand minaret, of which there hadbeen none like it [before] in islam" [6]. The text does mention the two mosques; the second was built on the site of Qaṣr al-Ḥajar, the Almoravid palace. And he attributes the foundation of this double mosque to ʿAbd al-Muʾmin[7], but he does not specify the date of this expansion project. A text by ibn Bashkuwāl indicates that the work on the new mosque began with its orientation in the early days of rabīʿ II 553 AH (2-10May 1158) and that this new mosque was inaugurated with the Friday prayer on 15 Shaʿbān / 11 September 1158. This text, however precious, is not without its doubts: the two dates are separated by only a few months and it seems very difficult to fit the entire construction of the mosque into this time frame, which must have begun well before May 1158, or continued well after September 1158! [8] The two Almohad mosques were similar in plan, but different for the faithful since they are not oriented towards Mecca in the same way, and the Almohads reoriented the second Kutubiyya 5° to the south in relation to the first Almohad mosque. It is assumed that a new mosque was built because the old one was badly oriented. However, the reorientation of the new mosque actually only aggravated the deficiencies in the direction of the qibla, which was now much more imprecise than that of the first mosque[9]. In Jacques Meunié's mind, the construction of the second mosque, like the abandonment of the first, would be subordinated to the increase or decrease in the population of Marrakech. But if it had only been a question of enlargement, would a new mosque have been built? It was enough to move the qibla wall. To the religious reason put forward by the inventors of the first Almohad mosque, to the demographic reason defended by J. Meunié, one could add a sentimental reason that it was the arrival of the Koran from Cordoba to Marrakesh that provoked in ʿAbd al-Muʾmin the idea of building or enlarging his mosque[10].

The Kutubiyya is trapezoidal in shape and consists of a prayer hall that is wider than it is deep, preceded by a long courtyard bordered by two galleries with four naves. The rear hall has seventeen naves perpendicular to the qibla wall, the central one being wider than the side naves. The 'transept' of the qibla is covered by five domes and is the same width as the middle nave. The entrance to the mosque is through eight side doors, which are envisaged to be pierced in the east and west walls. The minaret, located in the northeast corner of the mosque, as is the case with the Algerian Almoravid mosques and the Almohad mosque in Taza, is a square tower whose parapet is crowned with a frieze of sawtooth merlons and a lantern panelled with two-coloured [green and white] tiles and topped with a gadrooned cupola. The facades of the tower have a varied decoration in three registers; the first is decorated with a large mantled arch enclosing two paired openings; the second is underlined by a rectangular frame and decorated with an arched arch that borders two paired windows, while the third register contains four marked

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openings topped by a network of interlaced lobed arches [11]. No less than for the harmony of its plan, the Kutubiyya mosque, by the beautiful perspectives offered by its naves, by the purity of the lines of its arches, by the sobriety and width of its decoration, by the magnificent pulpit (minbar) of marquetry, and by the elegance of its minaret, can be considered as one of the summits of Western Muslim architecture [12].

Tests and scientific analyses, such as X-ray diffraction, X-ray fluorescence, and petrographic analysis, can be employed to evaluate potential restoration methods (including stripping techniques, protective systems, and the utilization of new consolidation or replacement materials) in order to establish the most effective restoration protocol for heritage buildings. These assessments consider factors such as treatment efficacy, final aesthetic appearance, and cost implications. Such evaluations are particularly vital for large structures undergoing restoration, as they serve to mitigate the risk of costly errors.

In the realm of masonry construction, the application of stabilization techniques involving lime, fibers, and other materials is systematically carried out to enhance the mineralogical, petrographic, and chemical properties of Kutubiyya materials [13, 14, 15]. However, the efficacy of this stabilization process hinges upon the specific mineralogical and granulometric composition of the materials. To delve deeper into this, mineralogical and chemical analyses are conducted to examine the elemental composition and proportions of mineral elements within Kutubiyya materials, and to understand their impact on the behavior of the Kutubiyya minaret.

Materials

Materials used in the construction of the Kutubiyya minaret

The main materials used in the construction of the Kutubiyya are the following.

2.1 Masonry

2.1.1 Main tower

The primary tower built using limestone masonry sourced from the quarries of JbelGueliz, likely incorporated reused blocks from the ancient ruins of Almoravid constructions. These limestone blocks possess a natural tendency to form uniform elements with rectangular sections, facilitating their ease of use in construction. Their dimensions diminish gradually from the edges towards the center and from the base to the summit, spanning from 10cm to over 2m. While the masonry pattern exhibits precision on the external walls with uniform blocks, internally, irregular blocks of varying sizes create an organic arrangement. Ornamental details in the register are typically fashioned from limestone pieces of appropriate shapes. Currently, the upper section of the main tower is undergoing modern restoration, including the implementation of reinforced concrete chinking.

2.1.2 lantern

The main structure of the lantern is built with carefully placed limestone masonry. Brickwork has been introduced at the openings and in the upper part of the lantern. These bricks, of average quality, were likely made from the clayey loam available in the region.

2.1.3 Ramps

The floors of the ramps are built with stone masonry. The vaults of the ramps are made of stone blocks which are laid elongated in the direction of the ramps.

2.2 Coatings

2.3.1External facades

The primary coating consists of lime mixed with silty sand, with lime being the predominant component, which adheres seamlessly to the limestone blocks and is utilized to create "false joints" to conceal any irregularities in the blocks. Within the registers, three types of plaster are observed. First, there is a white plaster coating utilized for shaping patterns. Second, there is a mixture comprising lime, plaster, and charcoal, which can be applied over the white plaster coating. Third, there is a lime-based coating that covers both the stones and the aforementioned intermediate coatings indiscriminately. Traces of modern mortar restoration, incorporating concrete, are evident in the upper portion of the tower.

2.3.2 Corridor.

On the corridor levels, two types of coating profiles are observed. Firstly, there's an 'earth and straw' coating directly adhered to the masonry stones, overlaid by a lime and straw coating, which in turn is covered by a plaster coating made of plaster and silty sand mortar. However, the 'earth and straw' plaster faces challenges with adhesion to the stones, resulting in significant detachment and swelling along the corridor walls. Consequently, at least three phases of restoration for the corridor walls, involving either plaster or lime, are required.

2.3.3 Ramps

The vaults of the ramps are typically covered with plaster mortar, which frequently develops a crack parallel to the ramp in the central part of the vault, along with numerous mortar detachments. Restoration of these vaults often involves up to four phases, predominantly utilizing plaster mortars.

2.3.4 Rooms

Plaster is used in the decorative motifs of the 7 chambers of the minaret.
The walls and domes are generally in good condition. Cracks in the plaster are restored with plaster.

Results and discussion

3.1 Mineralogical, petroghraphic and chemical characterization of Kutubiyya materials

Test program

The materials selected for mineralogical, petrographic and chemical characterisation were plaster and masonry stone.
Three samples were analysed.

Sample 1

It is a set of 3 types of materials (Figure.1.A):

a- An external coating (main coating).
b- An internal coating (intermediate coating)
c- A mortar (most common): This sample comes from a register, on the exterior facade side.

Sample2

It corresponds to the masonry stone (Figure.1.B).

Sample3

This sample corresponds to a plaster used in the registers (Figure.1.C).
These different samples, 4 in total, were subjected to mineralogical X-ray analysis, petrographic study (microscopic observation) and chemical analysis.

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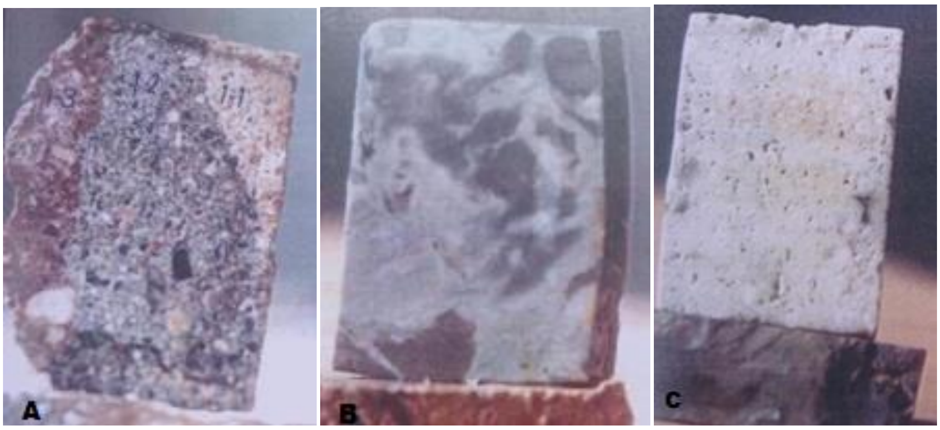

Figure1.Sampleof stone and coating

3.1.1 X-Ray Mineralogical Analysis

Sample 1-1

The diffractogram of this sample (Figure.2) shows characteristic diffraction peaks of calcite, gypsum, dolomite, quartz and clays.

The calcite peak is the most intense and therefore represents the most dominant mineral species in this sample. The presence of calcite and the lack of portlandite demonstrate that the binders are completely carbonated. As noted by Ammari et al. [14], quartz is not a binder but rather part of the fine sand fraction in the aggregate. The analysis indicated the presence of peaks for clays and gypse.

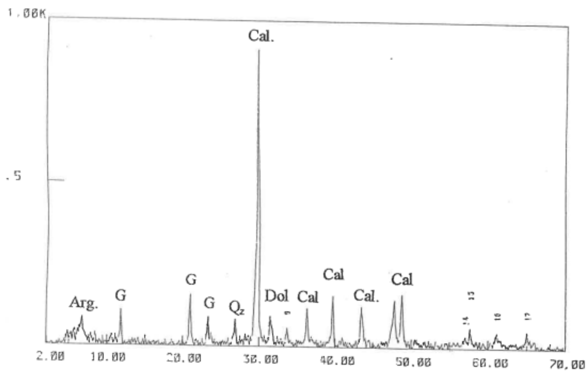

Figure 2. X-ray diffraction patterns of the sample 1-1

Sample 1-2

The diffractogram of this sample (Fig. 3) is comparable to that of sample 1-1. It also includes the same mineral species, namely calcite as the most intense, along with dolomite, quartz, gypsum, and clay.

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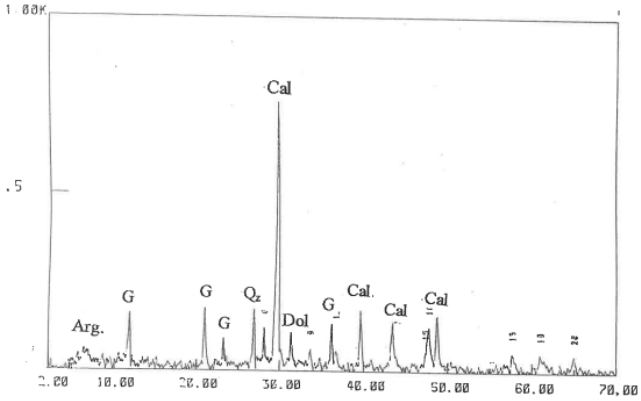

Figure 3. X-ray diffraction patterns of the sample 1-2

Sample 2

The diffraction peaks for this sample (Figure.4) correspond to calcite and clays. Less intense diffraction peaks corresponding to quartz, clays and dolomite are also noted.

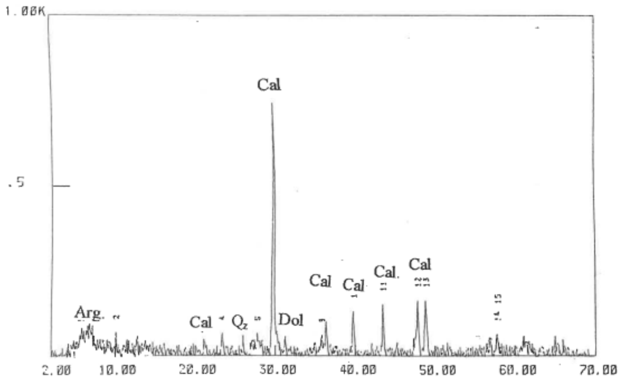

Figure 4. X-ray diffraction patterns of the sample 2

Sample 3

The diffractogram of this sample consists only of diffraction peaks related to gypsum (Figure.5).

Gypsum accelerates the gain in strength for lime-stabilized plaster[17]. However, gypsum also aids in accelerating strength development during the initial stages of hydration.Additionally, gypsum serves a complementary role as an accelerator, enhancing early strength development[16].

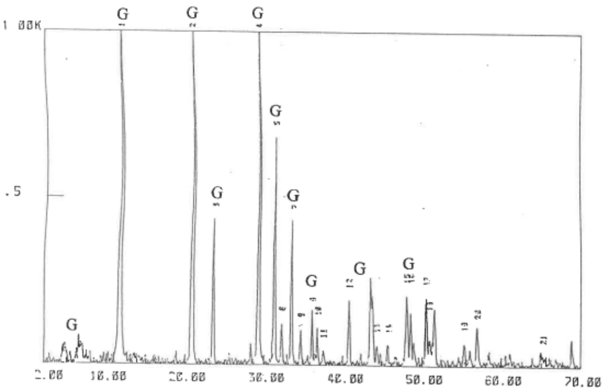

Figure 5. X-ray diffraction patterns of the sample 3

3.1.2 Petrographic Study

Sample 1-1

It represents the main rendering of the Kutubiyya (the most external). It is a fine, coherent material of beige colour (Figure.1.A). Microscopic observation shows that this sample is essentially formed of a fine matrix composed of micrite, clays and gypsum. This matrix, representing more than 80% of the material, binds figurative elements represented by angular and fine quartz grains (100 to 200 µm) and by calciticbioclasts composed of debris of organisms with a carbonate test (Figure.6.A)

Sample 1-2

This is an intermediate plaster between the main (external) plaster and the mortar. It is less fine than the previous one and has a granular aspect. This plaster is loaded with carbon particles which give the sample a dark colour (Figure. 6. A).

Microscopic observation shows that this coating does not differ much from the previous one; however, it is distinguished by its slightly coarser grain size and by the presence of carbonaceous particles ranging in size from 100-200µm to 2-3 mm. These particles, when they are large, show a characteristic cellular structure (Figure.6.B).

Sample 2

It is a compact, hard, fine-grained limestone block. It comprises light and dark grey patches of millimetre size. The contact between the different coloured patches is not straightforward but progressive (Figure.1.B).

Microscopic observation shows that this masonry stone corresponds to a very fine micritic limestone; the calcite crystals are very small (<10µm). The light-coloured patches are mainly formed of micrite, whereas the dark grey patches, often corroded by microcrystalline calcite and showing corrosion gulfs (Figure.6. C), are richer in detrital elements (quartz + clays). The quartz grains are very fine and angular (a few microns). The dark patches therefore correspond to a slightly sandy marly limestone (Figure.7.A) and the calcareous patches to zones of transformation of this original rock into a microcrystalline limestone (Figure.7.B). This transformation involved both the clays and the quartz grains, which were transformed into microcrystalline calcite. The rock is criss-crossed with microfissures filled with calcite. The masonry stone therefore originally corresponds to a marly, slightly sandy limestone that was partially transformed into a microcrystalline limestone during digenesis or slight metamorphism, without the circulation of solutions rich in calcium carbonate.

Sample 3

It is a beige material with a very fine grain size. However, it shows whitish concretions ranging in size from a few hundred µm to 3 mm in diameter (Figure.1.C). Microscopic analysis has shown that these concretions are formed from patches of crystalline gypsum, whereas the rest of the sample is formed from microcrystals of gypsum entangled in each other (Figure.7.C). These concretions would have formed by recrystallisation of the gypsum microcrystals well after the plaster had set.

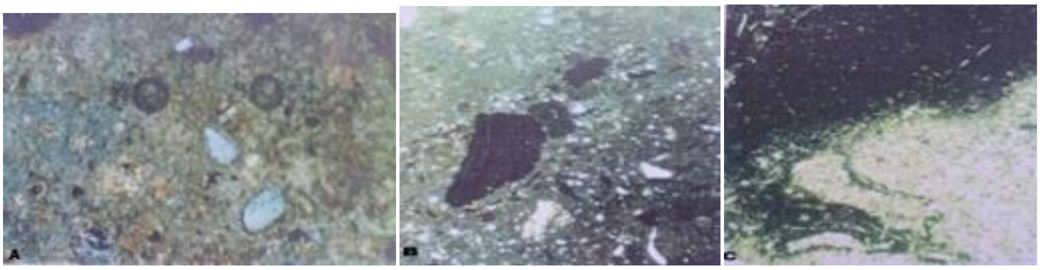

Figure 6.Petgohaphieof samples

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Figure 7. Petgohaphie of samples

3.1.3 Chemical study and determination of the composition

The different samples were analysed chemically. 8 major chemical elements, in addition to loss on ignition, were analysed: Si, Al, Fe, Ca, Mg, Na, K and S.

Sulphur was analysed gravimetrically, while all chemical analyses, expressed as percentages of oxides, are shown in Table 1 below.

For each sample, the results of the chemical analyses, combined with those of the petrographic and mineralogical analyses, made it possible to determine the mineralogical composition and therefore the dosage of the sample.

Indeed, the percentages of chemical elements determined by the chemical analysis are broken down among the mineral species in the sample, determined by petrography and X-rays, likely to contain these elements.

Table 1. Results of the chemical analyzes expressed as % of the total weight.

Sample N°	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	SiO_2	Perte au Feu.
1-1	3.47	1.5	29.97	2.053	0.81	2.57	6.16	18.15	31.13
1-2	4.74	2.02	25.9	1.74	1.38	2.94	6.222	25.4	27.9
2	7.35	3.53	29.94	2.14	1.75	3.98	0.86	23.36	24.74
3	0.58	0.29	28.92	0.23	0.74	1.98	40.81	1.65	20.93

Thus, all the sulphur in the sample is related to gypsum and anhydrite; the CaO analysed represents that of gypsum, calcite, anhydrite and dolomite; MgO represents that of dolomite and clays; SiO_2 is related to clays and quartz, while Al_2O_3, K_2O, Fe_2O_3 and Na_2O are totally related to clays

The mineralogical composition determined for all materials is given below:

Sample 1-1
Gypse 15%
Dolomite 10%
Calcite 45%
Argiles 20%
Quartz 10%

Sample 1-2
Gypse 14%
Dolomite 8%
Calcite 38%
Argiles 19%
Quartz 16%
Charbon= 5%

Sample 2
Calcite 55%
Dolomite 5%
Argiles 34%
Quartz 6%

Sample 3
Gypse 95%
Argiles 5%

Geotechnical characteristics of Kutubiyya materials

3-1- Recognition program

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The materials selected for the geotechnical characterization are stone and lime-based coating. The test program is summarized in Table 2.

Table 2: Geotechnical tests carried out on materials.

materials	Density	Porosity	Water content	Compressive strength	Modulus of elasticity	sonic velocity
Limestone	*2*	*2*	*2*	*2*	*2*	*2*
Limestoneplaster	*2*	*2*	*2*			

3.2. Limestone

It is in fact a slightly metamorphic marly limestone, affected bymicrofissures whose spacing varies from a few cm to 1 mm.

The geotechnical characteristics of the stone are summarized in Table 3.

Table 3: Geotechnical characteristics of the stone.

Density	Porosity in %	Water content in %	Compressive strength in bar	Modulus of elasticity in kg/cm2	sonic velocity in m/s
2.42	*2.2*	*<1*	*650*	*420000*	*4360*
2.46	*1.8*	*<1*	*760*	*580000*	*4450*

The relatively low density of the marly limestone, approximately 2.7, contrasts with its low porosity, averaging around 2%. This unique composition contributes to its distinct properties. Despite its negligible natural water content, the marly limestone exhibits medium compressive strength, as classified by rock mechanics standards outlined by Decre and Miller. Notably, its ratio of compressive strength to modulus of elasticity is high, further emphasizing its structural integrity. Moreover, the sonic velocity, averaging around 4400m/s, aligns with the characteristic nature of marl-limestone, affirming its suitability for various applications.

3.2 Limestone plaster

It is a plaster that is much lighter than mortar, with grain sizes generally less than 2mm.The geotechnical characteristics of the coating are summarized in Table 4.

Table 4. geotechnical characteristics of the coating

Density	*Porosity in %*	*Water content in %*
1.40	*34*	*3.4*
1.47	*27*	*2.8*

Thus, the plaster has a low density (average 1.44), a high porosity (average 30%) and a low natural water content (around 3%).

Synthesis

Finally, the different techniques used, i.e. X-ray analysis, microscopic study of thin sections, identification tests (density, porosity, water content, etc.), mechanical tests (strength and deformability) and geophysical tests (sonic velocity), were complementary and coherent for the identification of existing materials, which will make it possible to help in the preparation of substitute materials.

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4.1 Masonry stone

a- Existing materials

It is the result of a transformation, by a slight metamorphism, of marnocalcareous into micritic (microcrystalline) limestone.

This stone has a density of about 2.45 and strength and deformability characteristics of the order of magnitude of those of hard rock.

b- Substitute material

The restoration of the Kutubiyya should not necessitate a significant quantity of stone blocks, as they can be sourced from two main avenues. Firstly, blocks can be obtained from the reuse of materials salvaged from old ruins, particularly those in close proximity to the site. Alternatively, stone blocks can be sourced from the old quarries of JbelGueliz, where the extracted blocks will be utilized directly in the masonry process.

4.2 Coatings

a. Existing material

a.1 External facades

There are at least three coatings on the external facades: a main rendering based on lime, transformed into microcrystalline limestone, making up 55% of its weight, and plaster, which constitutes 15% gypsum by weight. The density of this coating is about 1.44, with porosity close to 30%. Beneath the main plaster at the level of the registers is a charcoal plaster. This plaster is similar to the main rendering but contains slightly less carbonate (46% by weight compared to 55%) and includes charcoal (5% by weight) in pieces smaller than 5mm. The introduction of charcoal is intended to facilitate deep carbonation of the lime. Additionally, there is a plaster composed of 95% gypsum and 5% clay, with gypsum crystals up to 3mm in size, used in the registers for shaping decorative patterns.

a.2. Interior facades

There are two types of plaster complexes on the walls of the ramps. The first consists of a plaster rendering composed of 85% gypsum and 15% anhydrite, resting on a rendering based on plaster, lime, and silt sand, with proportions of 50% gypsum and 10% silt sand. However, the plaster presents a serious issue of adhesion to the stone blocks.

b. Substitute material

The lime and silt sand are identical to those used for the plaster.

However, the grain size of the coating is finer than that of the mortar. The mixture of the binder (lime and/or plaster) and the silty sand must be passed through a fine sieve of 3mm. As for the plaster, we can use the plaster of Safi which has the same geological origin as the plaster of the Essaouira basin which was used in the construction of the Kutubiyya.

c. Dosage determination

Plaster coatings do not pose a problem of dosage as they consist only of gypsum plus anhydrite.

For the main (outermost) lime-based plaster, 55% calcite plus dolomite and 15% gypsum are used.

Correcting for the effect of carbonation of the lime and hydration of the gypsum, the volumetric dosage of the original mixture is restored as follows

- 55% lime (CaO)
- 10 to 15% plaster ($CaSO_4$)
- 30 to 35% silty sand.

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This is approximately:
- 2/3 binder (lime plus plaster)
- 1/3silty sand

Conclusion

This study on the building materials of the Kutubiyya has identified the main existing materials and provided guidance on alternative materials:

The masonry stone is a marly limestone with the characteristics of hard rock. The restoration of the Kutubiyya will require a reliable quantity of stones, which can come either from the ruins of old constructions near the site or from the old quarries of Jbel Gueliz.

The main exterior coating is based on lime and silty sand, with the addition of a percentage of plaster to accelerate setting. Here too, the lime is transformed into micritic calcite. The initial volumetric mix is 55% lime, 10 to 15% gypsum, and 30 to 35% silty sand, approximately 2/3 binder and 1/3 silty sand. There is perfect adhesion between this mortar and the masonry stone, likely due to the great similarity in the chemical composition of these two materials. This main plaster rests on another plaster layer made of lime and gypsum, into which charcoal is introduced, probably to facilitate deep carbonation. Silty sand is available in the Marrakech any supply problem.

Plaster is used on the exterior at the level of the registers for shaping decorative patterns and in the corridors for the vaults and walls. The plaster is transformed into microcrystalline gypsum, with crystals that can reach 3mm. The plaster from Safi should be suitable for the restoration of the Kutubiyya.

The walls of the corridors are covered with an earth and straw coating, which is then covered by a lime and straw coating. This coating poses a serious adhesion problem to the stones due to the incompatibility of the materials.

Finally, in light of this study of materials and previous studies, it seems that the restoration processes to be retained for the Kutubiyya are the "traditional processes" that respect the construction rules of the Kutubiyya.

Référence

1. Lévi-Provençal, E. (1928)*Documents inédits d'histoire Almohade, fragments manuscrits du "Legajo" 1919 du fond arabe de l'Escurial*, vol. I, Paris: Librairie Orientaliste Paul Geuthner.
2. Elkhammar, A. (2014), Contribution à l'étude des mosquées almohades', in Yannick Lintz, Claire Délèry et Bulle Tuil Leonetti (eds.) *Le Maroc médiéval. Un empire de l'Afrique à l'Espagne*. Paris: Hazan, Musée du Louvre, pp. 323.
3. Henri Basset, H. (1923) 'Une primitive mosquée de la Koutoubia à Marrakech', *Comptes rendus des séances de l'Académie des Inscriptions et Belles-Lettres* 67/3, pp. 248-252; Meunié, J. et Terrasse, H.(1952) *Recherches Archéologiques à Marrakech*, Publications de l'Institut des Hautes Etudes Marocaines, tome LIV. Paris: Arts et Métiers Graphiques, p. 84.
4. Deverdun, G., (1959) *Marrakech des origines à 1912*, vol. I. Rabat: Éditions Techniques Nord-Africaines, p. 172; Cenival, P. de. (1991) 'Marrakush', in *L'Encyclopédie de l'Islam*, nouvelle édition, vol. VI. Leiden - Paris: E.J. Brill - G.-P. Maisonneuve & Larose S.A., p. 581.
5. It takesitscurrentnamefrom the hundredbooksellers' shops thatadjoinedit. Jean-Léon l'Africain (16th century) reported in his Description de l'Afrique that: "Under the portico of this temple, thereused to be a hundredbooksellers' shops [fromwhichcomes the name of the Mosque of Booksellers, al-Kutubiyya], but nowthereis not a single one." L'Africain, J.-L. (1956) *Description de l'Afrique*, nouvelle édition traduite de l'italien parAlexis Épaulard, et annotée par Alexis Épaulard, Théodore Monod, Henri Lhote et Raymond Mauny, Paris:

Librairie d'Amérique et d'Orient Adrien-Maisonneuve, pp. 101-102; Meunié et Terrasse, *Recherches*, p. 88.

6. Anonyme. (1900) *L'Afrique septentrionale au XIIème siècle de notre ère*. Description extraite du Kitab El-Istibçar et traduite parE. Fagnan. Constantine: D. Braham fils, p. 181.
7. Basset, H., Terrasse, H., (1932)*Sanctuaires et forteresses Almohades*, collection Hespéris, Institut des HautesEtudes Marocaines, no. V. Paris: Larose éditeur, p. 104.
8. Deverdun, *Marrakech*, vol. I, pp. 183-184; Salmon, X. (2018) *Maroc almoravide et almohade. Architecture et décorsau temps des conquérants 1055-1269*. Paris: Lienart, p. 100-102.
9. Basset et Terrasse, *Sanctuaires*, pp. 104-105; Marçais, G. (1954) *L'Architecture musulmane d'Occident. Tunisie,Algérie, Maroc, Espagne et Sicile*. Paris: Arts et Métiers Graphiques, pp. 202, 205 ; Deverdun, *Marrakech*, vol. I, p. 181; Elkhammar, 'Contribution', p. 323; Stockstill, A. (2018) 'A tale of two mosques: Marrakesh's masjid al-Jami' al-Kutubiyya', *Muqarnas* 35, pp. 67-73.
10. Deverdun, *Marrakech*, vol. I, 182.
11. Marçais, *L'Architecture*, p. 205;Elkhammar, 'Contribution', p. 320; Touri, A. Ettahiri, A. S. et El Khammar, A. (2008) 'Aperçu sur l'organisation spatiale des mosquées marocaines', in *Spécificitésarchitecturales des mosquées au royaume du Maroc*. Rabat: Ministère des Habous et des Affaires Islamiques, p. 26.
12. Marçais, *L'Architecture*, 206.
13. Ammari,A., Bouassria,K. Tayyibi,A. Bouabid,H. Cherraj,M. CharifD'ouazzane,S. Ibnoussina,M. (2016)'Promoting the technique of grounding block compressed in the construction sectorby improving its mechanical behavior, *J. Mater. Environ. Sci.* 7 (10), pp. 3532–3537.
14. Ammari, A., Bouassria, K., Cherraj, M., Bouabid, H., D'ouazzane, S.C. (2017) 'Combined effect ofmineralogy and granular texture on the technico-economic optimum of the adobe andcompressed earth blocks', *Case Stud. Constr. Mater*. 7, pp. 240–248.
15. Ammari, A. Bouassria, K.Zakham, N. Cherraj, M. Bouabid, H. D'ouazzane, S.C.(2018)'Durability ofthe earth mortar: Physico-chemical and mineralogical characterization for the reduction of thecapillary rise', *MATEC Web Conf*, p. 1024.
16. Bhanumathidas, N., Kalidas, N., (2004) Dual role of gypsum: Set retarder andstrength accelerator.*The Indian Concrete Journal*.
17. Pizzo, P., Valek, J., Kozlovcev, P., Frankeova, D., Viani, A., (2024) 'Plasters and mortars from the theatre in NeaPaphos (Cyprus): Amultidisciplinary study', *Journal of Archaeological Science: Reports* 57,p.104595.