

## A morphological and geometrical study of historical minarets in the North of Algeria

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**Abstract:** The Islamic heritage constitutes a very precious treasure in Algeria, especially the places of worship (mosques), which reflect the symbol of this heritage. They are considered important landmarks in cities through architectural elements such as the dome and the minaret. Minarets are used by the muezzin to invite people to pray; they were previously built near the mosque or inside it, next to the prayer room. Later, they appeared as angular towers of mausoleums. This research is part of an analytical study of the minarets in Algeria during the medieval period (Bani Hamad, Moravid, Zayyanid, Marinid, and Ottoman) which were selected and then classified according to their various typologies (dimensions, forms, designs, etc.), and evolution over time. The main objectives of this work are to search for the forms that determine the typology of the minarets of each period. It also examines the correlation between dimensions and geometric parameters employed in the design conception of these minarets. The research followed a monographic method that relies on field observation and documentation, while including a thorough reading of history. The results show that the constant form of the vertical section of the minaret, with the same dimensions between the top and bottom, represents two-thirds of the main tower of the minarets. We also conclude that the square shape of the horizontal section of the minaret represents two-thirds of the main tower of the minarets, which expresses the most earthquake-resistant form. These dimensions play a pivotal role in enhancing the minaret's visual allure and architectural equilibrium, in addition to their earthquake resistance virtues.

**Keywords:** architectural style, Islamic heritage, minarets, geometric analysis, morphological analysis, mosque

## 1. Introduction

In the area of Islamic influence, minarets establish the identity of the mosques above which they rise as symbols of the Islamic religion. This symbolic element can be found in North Africa, the Middle East, Persia, the Turkish region, and Asia [1, 2]. These towers, called minarets, were first used by the muezzin to call for prayer and were erected next to the mosque or inside the courtyard adjacent to the prayer hall. At the beginning of the Islamic period, particularly during the Abbasid period, minarets were often physically detached from the body of the mosque. This phenomenon occurred as the capital of Islamic civilization shifted from Baghdad to Samarra, with only a superficial relationship to the main structure [3]. Later, they appeared as corner towers of mausoleums in some regions of the Islamic world. The minaret is the landmark of the Islamic city. Indeed, in the silhouette of the Islamic city, minarets appear as landmarks or elements structuring the urban profile, with their slender form reaching towards the sky. In the 1400 years of Islamic civilization, an exceptional variety of minarets has developed, with different architectural variations: their shapes varied from spiral, orthogonal, cylindrical, and square (Fig. 1), the size and particularly, the decoration of the four cross-sections [4].

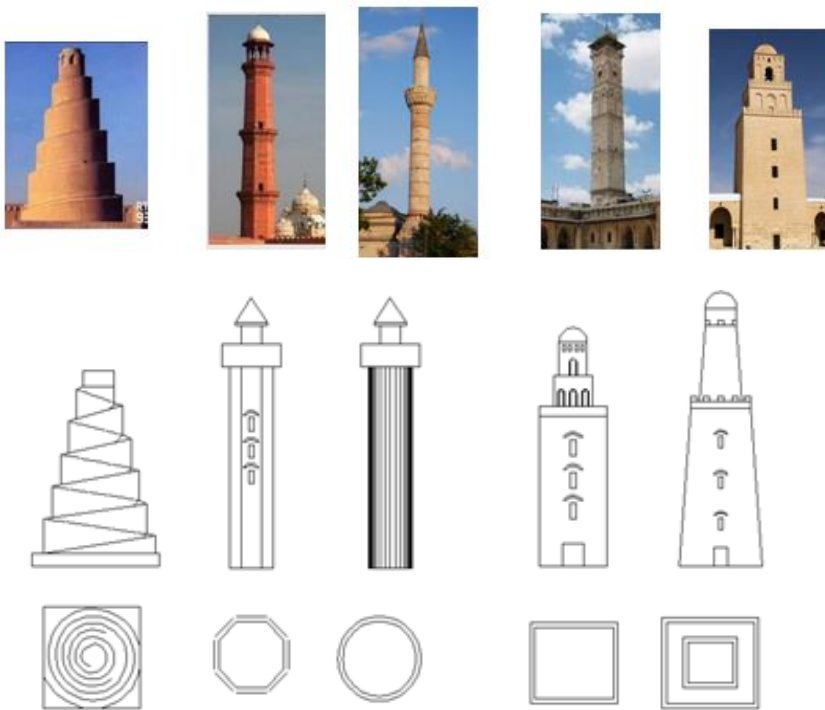


Fig. 1. Various shapes of a minaret, *source*: the authors

The architectural and stylistic monographs of minarets have rarely been studied by architects [5]. The majority of research work has been carried out either by archaeologists or by civil engineers who analysed the stability of minarets against earthquakes [6, 7]. İlker Kazaz et al. showed that minarets have better dynamic behaviour when the structure of the minaret is free-standing and not connected to the body of the mosque [8]. However, other

investigators have also confirmed that the geometrical properties (body height, slenderness, and cross-sectional area) have a significant impact on the dynamic behaviour of minarets [9].

A pioneering study was undertaken by Pavon on the geometrical shapes and dimensions of the minarets built in Andalusia (Spain). He found some important relationships, like the ratio of one-third ( $1/3$ ) between the base and the height of the lower part of the minaret, and one-fourth ( $1/4$ ) between the lower part's side base and the total height of the minaret [10].

Rafael Ortiz-Cordero et al. also studied the minaret in Andalusia, Spain, and demonstrated that determining some geometrical dimensions of the minaret parts allows for the classification of minarets' styles [10]. Edin Jahić conducted a comparative dimensional study on four Ottoman minarets made from wood in Bosnia and Herzegovina [9]. They confirmed that minaret width ranges from 5 to 8 meters and the minaret depth is usually 10–20% longer than the width.

Several earthquake analyses of old minarets in Algeria have proven that the minarets might be considered structurally safe according to seismic motion evaluation and the geometrical and material characteristics [11, 12]. Benabadi et al. found a relationship between the minarets in the north of Algeria from a morphological point of view and classified them into 14 categories, which are derived from Almohad minarets [5]. Sami Zerari et al. [3] also confirmed that the morphological and geometrical properties of the architecture of ancient minarets in the southern region are completely different from those of the minaret architecture in the north. This difference depends on the local cultural factors and climatic conditions.

## 2. Research methodology

Through a monographic and geometric study, the present research aims to investigate the relationship between the different formal compositions and dimensions of old minarets in Algeria. Firstly, a comparative study is conducted between a selection of 21 minarets, in order to highlight similar and dissimilar components of minarets (architectural and ornamental elements), and classify them. The dimensional and geometric properties of the selected minarets are then compared for the same purpose of classification.

## 3. Case study

Today, Algeria has more than 17,000 mosques from all historical periods, most of which date back many centuries [13, 4]. Twenty-one (21) minarets of Algerian mosques were selected from the north of Algeria. The minarets built in the south of Algeria are excluded from this research due to their special architecture, which has been deeply affected by the Saharan climate [3]. The choice of mosques in the northern part of the country was also made according to the collected data and available scientific resources. The minarets considered the most representative samples of specific historical periods were selected for this investigation. However, some very famous minarets have been excluded from this study; for example, the Ketchaoua mosque of the Ottoman period, because it underwent several modifications during the French colonial period [14].

This research examines the architecture of the selected minarets and their evolution through the five historic periods known to have marked the history of Northern Algeria: i) Bani Hamad, ii) Moravid, iii) Zayyanid, iv) Marinid, and v) Ottoman period (Fig. 2).



1-  
Bani Hamad  
Bani Hamad



2-  
Bani Hamad  
Old big mosque  
of Constantine



3-  
Bani Hamad  
Great mosque of  
Bejaia



4-  
Almoravid  
Great mosque of  
Algiers



5-  
Almoravid  
Big mosque of  
Nadrouma



6-  
Almoravid  
Great mosque of  
Tlemcen



7-  
Marinid  
Mansourah



8-  
Marinid Sidi  
Abou Mediene



9-  
Marinid  
Sidi El Haloui



10-  
Zayyanid  
Agadir



11-  
Zayyanid  
Michwar



12-  
Zayyanid  
Awlad Al-Imam



13-  
Zayyanid Sidi El  
bana



14-  
Zayyanid Sidi  
Brahim



15-  
Ottoman Ali  
Betchine



16-  
Ottoman  
La pêcheurie



17-  
Ottoman Djich



18-  
Ottoman Sidi  
Abed Rahmane  
TAALIBI



19-  
Ottoman – Old mosque of Tiaret



20-  
Ottoman – Salah BAY



21-  
Ottoman – Hassan Bacha

Fig. 2. Mosques from five periods in Algeria, *source*: the authors

### 3.1. The studied historical periods

The locations of mosques in Algeria were traced during different periods [15]. This periodization, especially for Northern Algerian mosques, differs from the historical

periodization of the different states that ruled these territories, since one architectural period can overlap with several historical periods: the Bani Hamad, Moravid, Zayyanid, Marinid, and Ottoman periods [16].

1007–1152 – *the reign of the Hammadids* (the reign of local rulers from the Berbers of the Middle Maghreb-Algeria); 1052–1147 – *the reign of the Almoravid dynasty* (reign of rulers from the Berbers of the Western Maghreb-Morocco); 1147–1235 (1269) – *the reign of the Almohad dynasty* (reign of rulers from the Berbers of the Western Maghreb-Morocco); 1215–1485 – *the reign of the Marinid dynasty* (reign of rulers from the Berbers of the Western Maghreb-Morocco); 1235–1556 – *the reign of the Zayyanid dynasty* (the reign of rulers from the Berbers of the Middle Maghreb-Algeria); 1554–1830 – *the rule of the Ottoman Empire*; 1830–1962 – *the French colonial period*, is distinguished by the transformation of many mosques into churches, where a large number of minarets were transformed into bell towers or even demolished (Fig. 3).

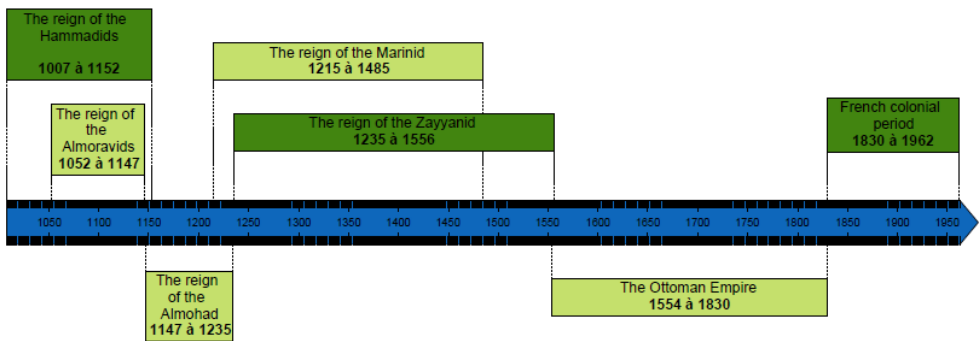


Fig. 3. Timeline of five periods in Algeria, *source:* the authors

### 3.2. Localization

Algeria is the largest country in Africa with an area of 2,381,741 km<sup>2</sup>, spread over fifty-eight (58) provinces, the majority of which are located in the northern part of the country. The distribution of the selected samples representing the four periods is related to the geographical expansion of each period. For example, the famous great minaret of the Bani Hamad period is located in the city of M'Sila, which was the capital of the Hammadids. On the other hand, the Algerian mosques dating back to the Almoravid, Marinid, and Zayyanid periods are concentrated in the city of Tlemcen, which was the historical capital at the time [15]. However, the mosques from the Ottoman period are spread over several cities in Algeria. According to Nabila's research, the greatest number of mosques in Algeria date back to the Ottoman period, and they are spread over several cities in the north of Algeria [17]. The Ottoman mosques selected for this study are located in the capital (Algiers), as well as in the cities of Annaba, Oran, and Tiaret [18] (Fig. 4).

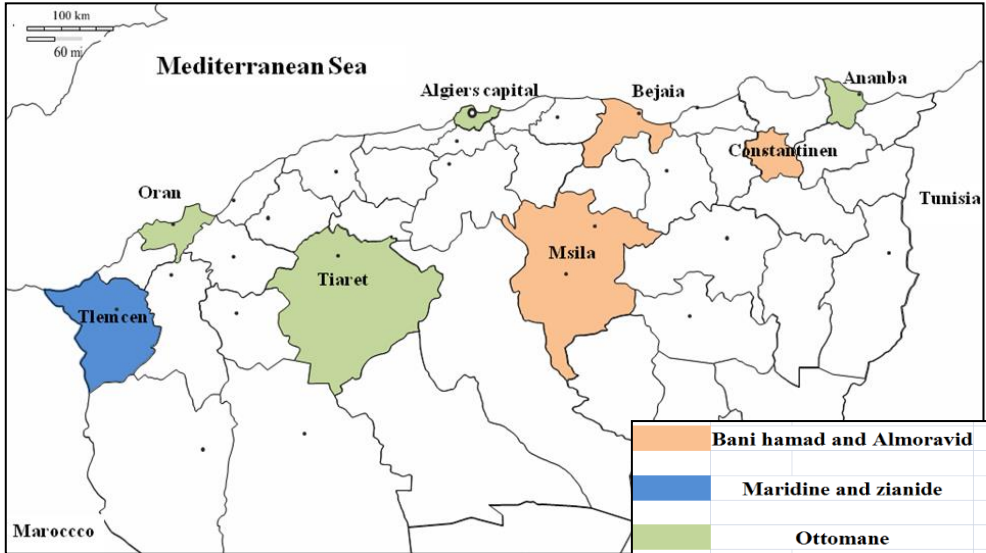


Fig. 4. Localization of Mosques studies in Algeria, *source*: the authors

### 3.3. Interpretation

[Table 1](#) shows the selected mosques for each period with their location, year of construction, and area. The majority of the mosques are typical five-prayer mosques (Masjids), except for Mansourah and Bani Hammad, which are congregational mosques (Jama'). For this reason, they have been built on the periphery and were attributed with a very large space.

For each mosque, we have also studied the position of the minaret, its height, and the main materials of construction used.

1. As shown in [Table 1](#), the majority of the minarets are located in the North of the mosques (about 50%), except for the 3 mosques (Michwar, Sidi Abed Rahmane Taalibi, and Hassan Pacha). These minarets are located in the South of the mosque, particularly in the South East, whereas the northern location of minarets varies in the East, Centre, and West.

2. The material used for the construction of the minarets was local; generally made of stone in the period of Bani Hamad. However, in the period of Almoravid, Marinid, and Zayyanid, they used brick and later, during the Ottoman period, stone was used again as a construction material.

3. In Islamic architecture, there is always a relationship between the splendor of the Maghreb's mosque and the height of the minaret as an important architectural element [13]. Therefore, the ratio (R) between the minaret height and the mosque area was studied, and 3 typologies were highlighted in this regard:

- a) Small mosque, with a ratio of  $R \leq 5/100$ : This includes all the mosques of the Bani Hamad, Marinid, and Zayyanid periods except the Bani Hamad mosque, the Big mosque of Algiers, and Mansourah mosque.
- b) Medium mosque, with a ratio of  $R \geq 3/100$ : Represents all the mosques of the Ottoman period.
- c) Large mosque, with a ratio of  $R \geq 1/100$ : This includes the Bani Hamad mosque, the Great mosque of Algiers, and the Tlemcen and Mansourah mosques.

Table 1. Details for Mosques from five periods in Algeria, *source*: own study

N°		Date		Dimensions			Minaret of mosques				
		City	Dynasty	Year	Length (m)	Width (m)	Area (m <sup>2</sup> )	Position*	Material	Height	Ratio**
1	Bani Hamad Mosque [11, 12]	Msila	Bani Hamad	1008	65.0	56.0	3640	North-West	Stone	25.00	1/100
2	Old great mosque of Constantine [19, 20]	Constantine	Bani Hamad	1135	24.0	22.1	530.4	North-West	Stone	24.70	5/100
3	Great mosque of Bejaia	Bejaia	Bani Hamad	1073	20.0	20.0	400	North-West		25.00	5/100
4	Great mosque of Algiers [21, 22]	Algiers	Almoravid	1097	48.0	40.0	1920	North-East	Solid brick	17.00	1/100
5	Great mosque of Nadrouma [23]	Tlemcen	Almoravid	1090	30.4	18.75	570	North-East	Solid brick	24.05	4/100
6	Great mosque of Tlemcen [24]	Tlemcen	Almoravid	1236	/	/	1373	North	Solid brick	29.15	2/100
7	Mansourah [25, 26]	Tlemcen	Marinid	1302	85.0	60.0	5100	North	Solid brick	47.00	1/100
8	Sidi Abou Mediene [27]	Tlemcen	Marinid	1339	28.45	18.9	537.7	North	Solid brick	27.50	5/100
9	Sidi El Haloui	Tlemcen	Marinid	1352	27.5	17.4	478.5	North-West	Solid brick	25.17	5/100
10	Agadir [28]	Tlemcen	Zayyanid	1236	/	/	500	North	Solid brick	26.60	5/100
11	Michwar [15]	Tlemcen	Zayyanid	1282	/	/	520	South-East	Solid brick	25.22	5/100
12	Awlad Al-Imam [29]	Tlemcen	Zayyanid	1310	/	/	250	North-East	Solid brick	12.25	5/100
13	Sidi El bana [30, 31]	Tlemcen	Zayyanid	1400	14	21	294	North	Solid brick	14.00	5/100
14	Sidi Brahim [28]	Tlemcen	Zayyanid		19.0	15.4	292.6	North-West	Solid brick	16.55	5/100
15	Ali Betchine [32, 33]	Algiers	Ottoman	1630	/	/	500	North-West	Stone	15.00	3/100
16	La pêcherie [34]	Algiers	Ottoman	1660	39.5	24.0	948	North-East	Stone	25.00	3/100
17	Djich	Algiers	Ottoman	1654	/	/	565		Stone	16.00	3/100

N°	Date	Dimensions				Minaret of mosques					
[34, 35]								North-West			
18	Sidi Abed Rahmane TAALIBI [34]	Algiers	Ottoman	1696	/	/	580	South-East	Stone	16.00	3/100
19	Old mosque of Tiaret	Tiaret	Ottoman	1612	24.0	20.0	720	North-East and West	Stone	24.00	3/100
20	Salah BAY [33, 20]	Annaba	Ottoman		38.45	20.9	803.6	North-East	Stone	22..00	3/100
21	Hassan Bacha [20]	Oran	Ottoman	1796	/	/	1250	South-East	Stone	33.00	3/100

\* Position regarding the mosque, \*\*The ratio of the minaret’s height to the mosque’s area.

#### 4. Comparative morphological study

The comparative studies are expected to contribute to the knowledge of the architectural commonalities and differences in building designs [36, 37]. In general, the minaret is composed of architectural elements and other decorations (ornamentation). According to morphological analysis, the studied minarets are divided into various autonomous segments with a similar structure [38].

##### A – Architectural Elements:

- Base (B): It is located in the lower part of the minaret.
- The Main Tower (M): This is the tallest and most significant element of the minaret, often enclosing a staircase.
- The Balcony (B1): It is usually a small overhanging platform located between the main tower (M) and the lantern (L).
- The lantern (L): It is the element that covers the main tower; it is a structure with a square or rectangular plan, pierced with windows, or rather a slender shape, often surmounted by a dome, a roof, or a spire in the frame.

##### B – Ornamentation Elements:

- Rhombus (R): It is a wall decoration specific to Islamic architecture, located at the level of the main tower.
- Merlon (M1, M2): It is a mode of ornamentation through the appearance of the solid part of brick or stone.
- Earthenware (E1): Generally, it decorates the ends of the lantern.
- End Ornamental (E): The minarets are often surmounted by three balls and a crescent. These three balls symbolize the three worlds; the crescent represents the fourth world, that is, the inaccessible world of divine majesty [1].
- Corner (C1, C2, C3): Usually ornate and protruding on the upper part, it is often horizontal.



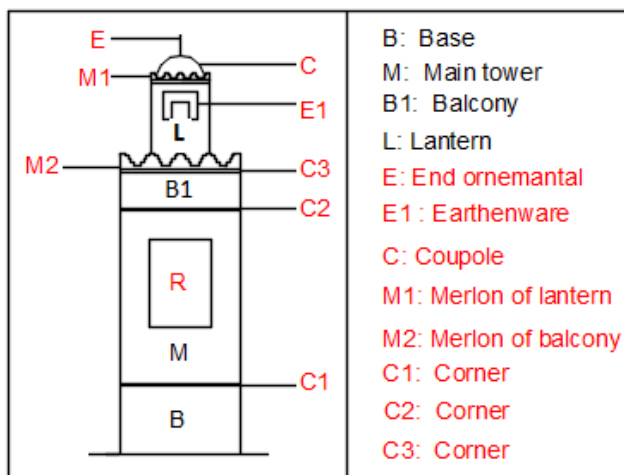


Fig. 5. Architectural vocabulary of minarets, *source:* the authors

Table 2. Morphological analysis of the minarets, *source:* the authors

N°	Mosques	Period	Architectural elements				Total	Ornamentation elements							Total			
			B	M	B1	L		E	E1	C	M1	M2	C1	C2		C3	R	
1	Bani Hamad Mosque	Bani Hamad		X		X	2							X			X	2
2	Old great mosque of Constantine	Bani Hamad	X	X	X	X	4	X	X	X	X	X	X	X	X	X	X	9
3	Great mosque of Bejaia	Bani Hamad	X	X	X	X	4	X	X	X	X	X	X	X	X	X	X	9
4	Great mosque of Algiers	Almoravid		X	X	X	3	X	X	X	X	X	X	X	X	X	X	9
5	Great mosque of Nadrouma	Almoravid		X	X	X	3	X	X				X	X	X	X	6	
6	Great mosque of Tlemcen	Almoravid		X	X	X	3	X	X	X	X	X	X	X	X	X	9	
7	Mansourah	Marinid		X		X	2								X		X	2
8	Sidi Abou Mediene	Marinid		X	X	X	3	X	X	X	X	X	X	X	X	X	X	9
9	Sidi El Haloui	Marinid		X	X	X	3	X	X	X	X	X	X	X	X	X	X	9
10	Agadir	Zayyanid		X	X	X	3	X	X	X	X	X	X	X	X	X	X	9
11	Michwar	Zayyanid		X	X	X	3	X	X	X	X	X	X	X	X	X	X	9
12	Awlad Al-Imam	Zayyanid		X	X	X	3	X	X				X	X	X	X	6	
13	Sidi El bana	Zayyanid		X	X	X	3	X	X	X	X	X	X	X	X	X	9	
14	Sidi Brahim	Zayyanid		X	X	X	3	X	X	X	X	X	X	X	X	X	9	
15	Ali Betchine	Ottoman		X	X	X	3	X		X	X	X	X	X	X	X	8	
16	La pêcheirie	Ottoman		X	X	X	3	X		X	X	X	X	X	X	X	8	
17	Djich	Ottoman		X	X	X	3	X		X	X	X	X	X	X	X	8	
18	Sidi Abed Rahmane TAALIBI	Ottoman		X	X	X	3	X		X	X	X	X	X	X	X	8	
19	Old mosque of Tiaret	Ottoman	X	X	X	X	4	X		X	X	X	X	X	X	X	8	
20	Salah BAY	Ottoman		X	X	X	3	X		X				X			2	
21	Hassan Bacha	Ottoman		X	X	X	3	X	X	X	X		X	X	X	X	8	

#### **4.1. Interpretation of morphological study**

The morphological study has shown that all the minaret specimens have three architectural elements (the main tower (T), the lantern (L), and the balcony (B1)) except for the minarets of Mansourah and Bani Hamad, which do not have a balcony.

Two minarets, those of the old Great Mosque of Constantine and the Great Mosque of Bejaia, also have an additional architectural element known as the base (B).

It is worth mentioning that the three architectural elements (the main tower, the lantern, and the balcony) are almost omnipresent in all the studied minarets. They are considered principal elements in all the minarets, the most attractive segments of their architecture, and constitute a sort of identity segments in all the minarets, with the exception of the two minarets that have a specific architecture.

Regarding the ornamental elements, they are also present in all the studied minarets, with the exception of the two minarets (Mansourah and Bani Hamad), which have only two ornamental elements. All the ornamental elements could be observed in the Zayyanid and Marinid minarets. However, one element (Earthenware) was absent in the Ottoman minarets, while the minaret of Salah Bay presents a simple facade and poor decoration.

From this study, the minarets can be classified into 4 classes:

- Class 1: Minaret of Mansourah and Bani Hamad with poor decoration, evidenced by the presence of two ornamental elements.
- Class 2: A resemblance of two minarets of different dynasties (Great Mosque of Nadrouma and Awlad Al-Imam) with the presence of 6 ornamental elements.
- Class 3: The Ottoman minarets, excluding Salah Bay, with 8 ornamental elements.
- Class 4: Full decoration with the presence of all the ornamental elements, representing the majority of Almoravid, Marinid, and Zayyanid minarets.

### **5. Comparative geometrical study**

Using geometrical analysis, the minarets are illustrated with two types of architectural documents: horizontal (section) and vertical (elevation), to study each fragment's shape and dimension (Fig. 6). The minarets are compared and classified according to the shape of the elevation, a section of the minarets, and their dimensions.

#### **5.1. Shape analysis**

From a chronological perspective, there is a clear relationship between the development of the method of construction and the shape of the minarets. According to the data collected in this study, there are three (3) types of elevations and four (4) types of sections.

The distribution of shapes for all the minarets can be observed in Table 3. The majority of the minarets (2/3) have a constant shape in elevation, except for those of Mansourah and Awlad Al-Imam, and they also have a square section, excluding two Ottoman minarets: Salah Bay with a circular section and the Old Mosque of Tiaret and Hassan Bacha with an orthogonal section.

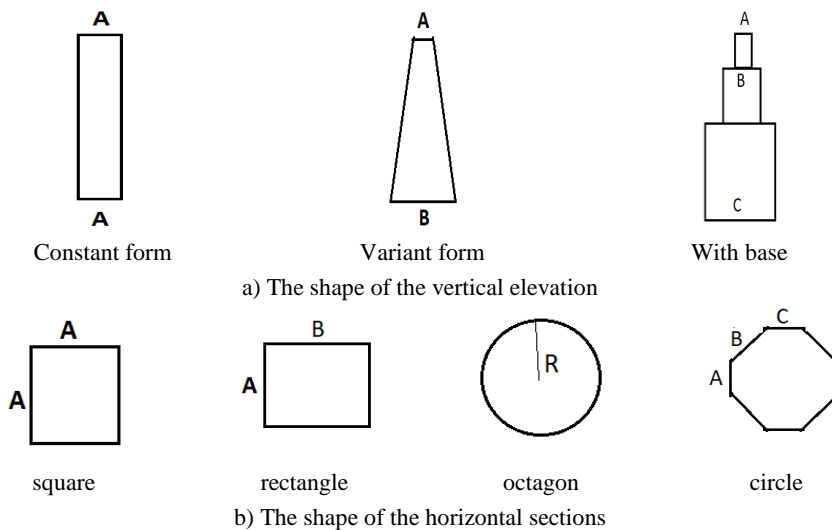


Fig. 6. Shape of the vertical and horizontal sections of the minarets, *source*: the authors

Table 3. Shape analysis of the minarets, *source*: the authors

N°	Dynasty	Vertical section			Horizontal section			
		Constant form	Variant form	With base	square	rectangle	octagon	circle
1	Bani Hamad Mosque	Bani Hamad	X				X	
2	Old great mosque of Constantine				X	X		
3	Great mosque of Bejaia			X	X			
4	Great mosque of Algiers		X		X			
5	Great mosque of Nadrouma	Almoravid	X		X			
6	Great mosque of Tlemcen		X		X			
7	Mansourah		X			X		
8	Sidi AbouMediene	Marinid	X		X			
9	Sidi ElHaloui		X		X			
10	Agadir		X		X			
11	Michwar		X		X			
12	Awlad Al-Imam	Zayyanid		X		X		
13	Sidi El bana		X		X			
14	Sidi Brahim		X		X			

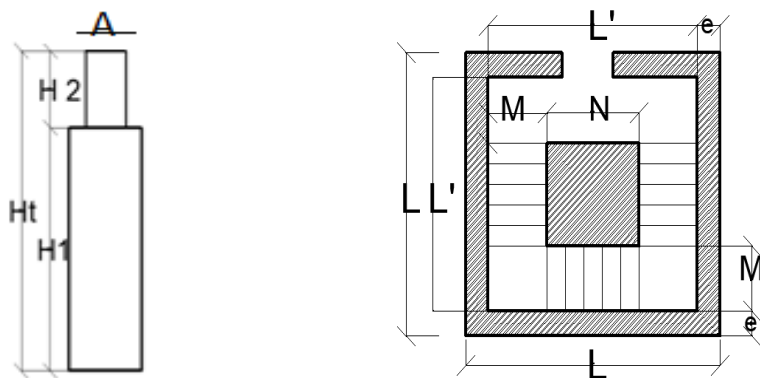
N°	Dynasty	Vertical section			Horizontal section			
		Constant form	Variant form	With base	square	rectangle	octagon	circle
15	Ali Betchine		X		X			
16	La pêcherie	X			X			
17	Djich	X			X			
18	Sidi Abed Rahmane TAALIBI	Ottoman	X				X	
19	Old mosque of Tiaret			X			X	
20	Salah BAY			X				X
21	Hassan Bacha	X					X	
Total		14	3	4	14	3	3	1
percentage		2./3	3/21	4/21	2/3	3/21	3/21	1/21

### 5.2. Dimensional analysis

Dimensional analysis is one of the important aspects of a geometrical study [39]. We used this type of analysis to determine some proportions applied in the design of the minarets. By knowing a few dimensions of old minarets, we can predict the origin of the minaret [10].

The comparative studies are expected to contribute to the knowledge of architectural commonalities and differences in ratios [36]. We studied three types of ratios that play a very important role in the design of these minarets.

We also studied the coefficient of variation for the dimensions of the main tower and the lantern, which represents the ratio of the standard dimensional deviation. This is a useful statistic for comparing the degree of variation from different minarets for each period.



A: width of the lantern, H1: height of the main tower, H2: height of the lantern, Ht: total height of the minaret

L: external length, L': interior length, e: thickness, N: length of the body of stairs, M: length of stairs, Ns: number of stairs

Fig. 7. Symbols for horizontal and vertical sections of the minarets, source: own study

Table 4. Dimensional analysis of the minarets, *source*: own study

N	Vertical section				Horizontal section					Ratio				Coefficient of variation				
	Dynasty	A	H1	H2	Ht	L	L'	E	N	M	Ns	L/Ht	A/H2	A/L	Main tower		Lanter	
		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)					H1	L	H2	A
1		3.60	/	/	24.70	6.50	5.50	1.00	1.20	1.10	50	1/4	/	1/2				
2	Bani Hamad	2.00	20.00	4.00	24.00	4.10	/	/	1.30	/		1/5	1/2	1/2	/	0.24	/	0.30
3		2.00	16.00	4.00	20.00	4.00	3.00	1.00	/	/	/	1/5	1/2	1/2				
4		1.50	14.00	3.00	17.00	3.50	/	0.80	/	/		1/5	1/2	1/2				
5	Almoravid	2.50	19.80	4.25	24.05	4.75	5.50	0.82	2.10	0.82	99	1/5	1/2	1/2	0.25	0.24	0.18	0.23
6		2.60	26.20	4.70	29.15	6.30	4.72	1.58	2.80	0.96	130	1/5	1/2	1/2				
7		/	38.00	9.00	47.00	10.00	2.48	1.10	/	1.33	/	1/5	/	/				
8	Marinid	1.88	23.70	5.40	27.00	4.30	3.21	0.60	1.70	0.75	86	1/5	1/3	1/2	0.28	0.41	0.26	/
9		2.00	20.35	5.32	25.17	4.67	3.29	1.38	1.78	0.78	88	1/5	1/3	1/2				
10		2.40	22.30	4.70	26.60	5.56	3.90	1.66	2.10	0.88	127	1/5	1/2	1/2				
11		2.32	19.30	5.92	25.22	4.95	3.83	1.58	2.32	0.91	88	1/5	1/3	1/2				
12	Zayyanid	1.00	9.65	3.45	12.25	2.98	2.10	0.55	1.01	0.55	44	1/4	1/2	1/3	0.32	0.24	0.22	0.34
13		0.90	10.5	3.50	14.00	3.50	3.00	/	/	/	/	1/4	1/4	1/4				
14		1.82	18.40	4.70	16.55	4.00	2.70	1.30	1.40	0.79	60	1/4	1/3	1/2				
15		1.32	12.60	2.40	15.00	3.50	2.66	0.84	1.35	0.65	44	1/4	1/2	1/3				
16		2.00	19.30	5.70	25.00	4.00	3.50	0.54	1.60	0.70	124	1/4	1/3	1/2				
17		1.50	13.00	3.00	16.00	3.50	2.50	0.50	0.83	1.10	48	1/4	1/2	1/2				
18	Ottoman	1.50	12.67	3.33	16.00	3.00	2.30	0.70	0.70	1.00	27	1/4	1/2	1/2	0.21	0.06	0.39	0.18
19		2.00	20.00	4.00	24.00	4.20	3.50	0.50	/	1.00	/	1/4	1/2	1/2				
20		1.50	13.00	3.00	16.00	3.20	/	0.55	/	/	/	1/4	1/2	1/2				
21		1.60	30.00	3.00	33.00	6.00	/	0.60	/	/	180	1/4	1/2	1/4				

### 5.3. Interpretation of dimensional analysis

Table 4 displays measurements for analyzing the dimensions of the minaret during the five periods, and it also illustrates the dimension relationship within the minaret's structure.

Bani Hamad Period: The height of the minaret is extremely close to 24 m, with a large thickness because they are built with stone.

- Almoravid Period: The height of the minaret is limited between 17 and 19 m, with a large thickness of the wall.
- Marinid Period: The height of the minaret is limited between 25 and 27 m, except Mansourah, which is the highest old minaret in Algeria with 47 m.
- Zayyanid Period: The height of the minaret varies, where Awlad Imam is the smallest minaret of all the studied samples. The thickness of the wall is similar to the Marinid period, except for Awlad Imam, due to its small size.

Ottoman Period: The height of the Ali Betchine, Djich, and Sidi Abed Rahmane Taalibi minarets are very close to each other, with no significant difference. The minarets of La Pecherie and the Old Mosque of Tiaret are also between 24 and 25 m. The highest Ottoman minaret is Hassan Pacha with 33 m.

Three ratios were studied:

- The relationship between the overall height and the external length of the minaret ( $L/Ht$ ) = 1/4 for Ottoman minarets.
- The relation between width and height of the lantern ( $A/H2$ ) = 1/2.
- The relation between the width of the lantern and the overall height of the minaret ( $A/L$ ) = 1/2.

The coefficient of variation for the dimensions of the main tower and the lantern was also studied. All the coefficients are less than 0.5, which explains why there is not a large difference between the dimensions.

The coefficients of variation are distributed between 0.20 and 0.30, with the exception of the external length of the lantern in the Marinid period with a larger gap of 0.41. Whereas the minarets of the Ottoman period present a very small gap of 0.06.

## 6. Conclusions

The minaret is an important element of Islamic architecture. With its various forms, styles, and characters, it has become a symbol of the Muslim community. This research contributed to the knowledge of old minarets and focused especially on the morphological and geometrical specificities of the architecture of ancient minarets in Northern Algeria.

Through this study, we have concluded that all minarets exhibit essential architectural components: a base, a lantern, and a balcony. However, the exceptional minarets stand out as monumental mosques. It has also been possible to categorize the minarets into 4 classes:

- Class 1: With poor decoration, evidenced by the presence of two ornamental elements.
- Class 2: With the presence of 6 ornamental elements.
- Class 3: With 8 ornamental elements.
- Class 4: Full decorations with the presence of all the ornamental elements, representing the majority of Almoravid, Marinid, and Zayyanid minarets.

The historic minarets in Algeria, like many historical architectural structures, possess various aspects that are interconnected and hold significance. Here's a description of the relationship between dimensions in a historic minaret in Northern Algeria.

The rectangular shape of the main tower of the minaret represented the number 2/3, with the same dimensions between the top and bottom, whereas the square shape of the section of the main tower of minarets represented the number 2/3.

Three common geometrical ratios have been found in the current study:

- i) The relationship between the overall height and the external length of the minaret ( $L/Ht$ ) is 1/4 for Ottoman minarets.
- ii) The relationship between the width and height of the lantern ( $A/H2$ ) is 1/2.
- iii) The relationship between the width of the lantern and the total height of the minaret ( $A/L$ ) is 1/2.

The results obtained show that the proportions between different parts of the minaret, such as the base, the body, and the spire, are carefully considered in the studied mosques. These dimensions contribute to the minaret's aesthetic appeal and architectural balance.

This research provides results that can be useful as a database for future studies in identifying different historical minarets and classifying them based on either the presence of ornamentation or through dimensions and geometric form.

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