# Morphometric method of daylight factor Kairouan great mosque case

**Sonda Kammoun[1], Abdelkader Ben Saci[2]**

[1]Equipe M2a, ED SIA, Ecole Nationale d'Architecture et d'Urbanisme, Tunis, Tunisia
[2]CRESSON, Ecole Nationale Supérieure d'Architecture de Grenoble, Grenoble, France

ABSTRACT: Natural light is a fundamental component of the architectural form. Understanding the interaction of natural light and building's form informs about the architectural knowledge in the field of energy efficiency and improves the building quality and performance. It is often approached either as a physical phenomenon in connection with functional aspects of comfort and needs, or as a sensory phenomenon in connection with the sensory perception of the constructed environment. We propose another way, which is to handle the natural light in architecture as a measurable morphological phenomenon.

This paper proposes a morphometric method for characterizing and measuring the daylight form. The morphometry concerns the digital simulation of the daylight factor in the great mosque of Kairouan. The selected software for daylight factor simulation is Radiance in Ecotect.

The aim of this work is to convert the sensitive into the tangible, with a view to understand how to design buildings' morphology while ensuring mastery of natural light.

Light is a measurable form. Designing with the natural light can be optimized through the analysis of its morphology.

KEYWORDS: Morphometry, Daylight Factor, Mosque's Architecture, Radiance in Ecotect.

## INTRODUCTION

> "*Architects in planning rooms today have forgotten their faith in natural light. Depending on the touch of a finger to a switch, they are satisfied with static light and forget the endlessly changing qualities of natural light, in which a room is a different room every second of the day*" (Kahn 1996, 218).

Natural light is the main topic of several architectural research projects that can be classified in three approaches. The first one considers light as a physical phenomenon and studies its performance through the simulation of the light distribution and the testing of software light simulation. In this context, Miguet (2000) offered a numerical model for the simulation of natural light in urban plan, Maamri (2004) and Namburi (2006) outlined "*an approach to compare the various most commonly used daylighting/ lighting design software programs available in the market* " and evaluated their performances "*based upon their capabilities to fulfill the assigned tasks by the users/lighting designers* ".

The second studies the integration of daylighting in design process. Tourre (2007) suggested a method which concretizes lighting ambience intentions, by producing geometrical properties of openings. "*The designer is allowed to express his lighting ambience intentions through physical lighting parameters*" (Tourre 2007,VII). More recent studies propose a design support method that takes into account "*the early design step features and helps designers to integrate their daylight atmosphere intentions in project*" (Gallas 2013).

The third implied that light is considered to be a sensitive phenomenon in relation with the perception of the built environment (Chelkoff 1990, Milone 2007, Michael 2012). Some researchers were interested in the space perception through the evaluation of comfort such as Dubois who shows that the diversity of luminous ambiences, produced by the integration of natural lighting in the internal areas, is capable of creating comfortable areas (2006).

In the current context of sustainable development, this work proposes another way that considers natural light in architecture as a measurable morphological phenomenon. In this paper, we offer to assess the daylight in the great mosque of Kairouan through a morphometric approach in order to characterize the space distribution of natural light in correlation with the built space.
The objective is to develop a method to measure the form of natural light based on the morphometric analysis and the computer simulation of the daylight factor (DF). In a more general way, the aim is to convert the sensitive into tangible, in a perspective to design buildings morphology while ensuring mastery of natural light.

## 1.0 MATERIAL AND METHOD

### 1.1. Presentation of the case study

> *"I am, one more time, in the great Mosque of Kairouan, in the centre of this huge courtyard bathing in natural light. Deep thinking makes me abolish the tiles which regularly cover the ground, the minaret which points up to the sky, the prayer hall which looks out over it and the porticos which attain the horizon"* (Sebag 1977).[i]

We are proposing to study the case of the great mosque of Kairouan, the oldest and most prestigious place of worship in North Africa (Gabrieli). The mosque of Uqba or great mosque is located in the Nord-East of the fortified surrounding wall of the Medina of Kairouan (Fig. 1).

**Figure 1:** Arial view of Kairouan Great Mosque or Mosque of Uqba in Tunisia. Source :( Filkr, Momin Bannani 2014).

Established in 670 by Oqba Ibn Nafeu at the founding of Kairouan, the mosque was destroyed about 690 by the Berbers. It was rebuilt, renovated and expanded by Arab governors Hassan Ben Noman (703) and Bichr Ibn Safouan (724) (Saladin, 1899). It acquired its essential features under the Aghlabides (9th century) with Ziadet Allah 1$^{st}$ who reconstructed the mosque once more (836).

The Kairouan great mosque looks like a fortress with their 2m thick exterior walls. The building is a large irregular quadrilateral.Its dimensions are approximately 135 m by 75 m. It covers a total area of 9000 m$^2$.

The hypostyle prayer hall takes a rectangular shape divided into seventeen naves of eight bays (Fig. 2). It counts about 400 columns reused from Roman. The Mihrab is located in the middle of the southern wall and covered by the dome based on an octagonal drum with slightly concave sides, pierced by eight windows based on a square base. The courtyard and the galleries that surround cover an immense area with a length of about 90 meters and 72 meters in width (Fig. 3).

**Figure 2:** Interior view of the prayer hall of the Kairouan mosque. Source: (Author 2013)

**Figure 3**: Interior view of the galleries. Source: (Author 2013)

### 1.2. Method

We chose the Daylight Factor (DF) as an analyzing natural light indicator in the mosque. This notion allows to assess the relationship between internal illumination and the availability of the natural light. It is defined by the International Committee of Lighting (CIE) as a ratio that represents the amount of illumination available indoors, related to the outdoor existing illumination at the same time. Expressed in percentage, the DF should be calculated under the CIE overcast sky condition.

The daylight simulation was performed using Radiance in Ecotect Analysis. According to Marsh, Radiance is:

> "*Currently the most accurate tool available for both daylighting and artificial lighting analysis. It uses a two-pass, hybrid, backwards-raytracing algorithm that can handle complex geometry and sophisticated material definitions. Moreover, it is one of only a few analysis tools that can calculate illuminance levels* ". [Marsh 2007]

We also performed tests using several software (3Ds Max Design, Daysim, Ecotect, solene), we considered a case study, and we compared between the experimental measurements taken on-site with tow luxmeters and the simulation results. The Radiance software in Ecotect gave the closest results to experimental measures that joins Marsh conclusion.

We then proposed to study the form of the natural light distribution through a morphometric approach. The morphometry is a tool that allows to measure form and to clear its invisible structure. It is an *operation of spatial forms conversion into quantitative representations* (Ben Saci, 2000).

The objective of the morphometric analysis is to understand forms, defined in epistemological terms, by an objective understanding of forms and, in pragmatic terms, by a systematic characterisation tool of morphological information allowing to compare and to categorise forms, and to disclose invisible morphological structures from visible forms (Ben saci, 2000).

Morhometric calculation is performed by Morgine software, developed as part of doctoral research projects directed by Ben Saci. It characterises forms by a descriptor representing an information distributing profile of DF in the mosque.

### 1.3. Application of the method

The first step is the realisation of the Kairouan great mosque numerical model by using surface modelling, designed in 3Ds Max Design (version 2010). This model was accomplished by setting up a methodology to ensure perfection and realism that could guarantee a better quality and accuracy of subsequent calculations. In fact, we collected and rectified drawing plan and facades in situ, and we took photos of each detail to create the 3D model (Fig. 4).
We chose to assimilate openings with holes, it is about the case of maximum penetration of natural light in the mosque (Fig. 5).

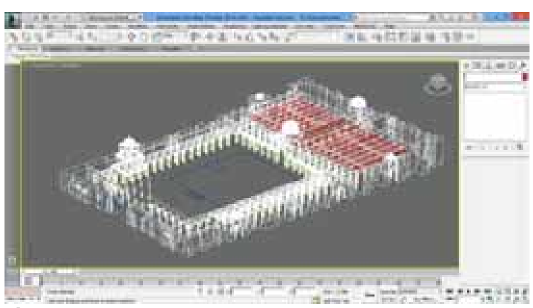

**Figure 4:** 3D model of the great mosque of Kairouan under 3Ds Max Design 2010. (Auteur, 2014)

**Figure 5:** 3D view of the great mosque of Kairouan model. Source: (Auteur 2014)

We then imported the 3D model under DXF format in software Ecotect Analysis; we specified the scale of the drawing, the materials of objects and the characteristics of the site (latitude, longitude and North position).

We specified the grid of sensor points for analysis by specifying its size and cell number. We have chosen 3 meter as a distance between points, since the greater the number of cells the greater the accuracy of the grid calculation, but the longer it will take (Table 1).

**Table 1**: Definition of the analysis grid dimension sunder Ecotect. Source: (Author 2014)

| Mosque dimensions | | | Number of cells | |
|---|---|---|---|---|
| width | length | height | X axis | Y axis |
| 82m | 133m | 14m | 28 | 45 |

We exported the model with the analysis grid to radiance. Simulation was performed in the case of a CIE overcast sky, materials were defined according to the database of Ecotect and an indirect reflections value of 5 (Fig. 6).

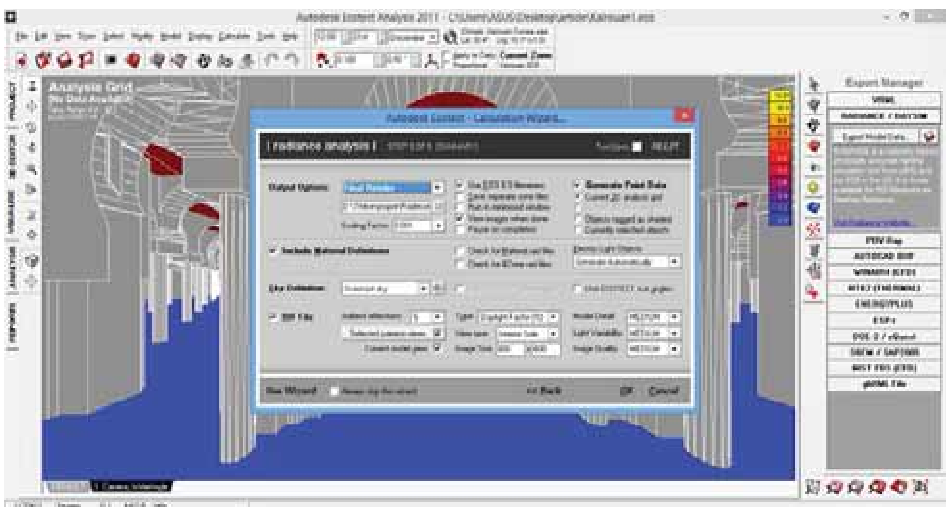

**Figure 6:** Ecotect software interface when exporting to radiance analysis. Source: (Author 2014)

The simulation results are represented by a DF cartography and a table of values exported in CSV format.

Then we performed a morphometric calculation by Morgine software, following these steps:
• Importing the values table in CSV format under Morgine;
• Calculating descriptors (Fig. 7);
• Exporting results in a CSV file, exploitable under Excel.
• Generating curve which translates the analyzed object morphometry.

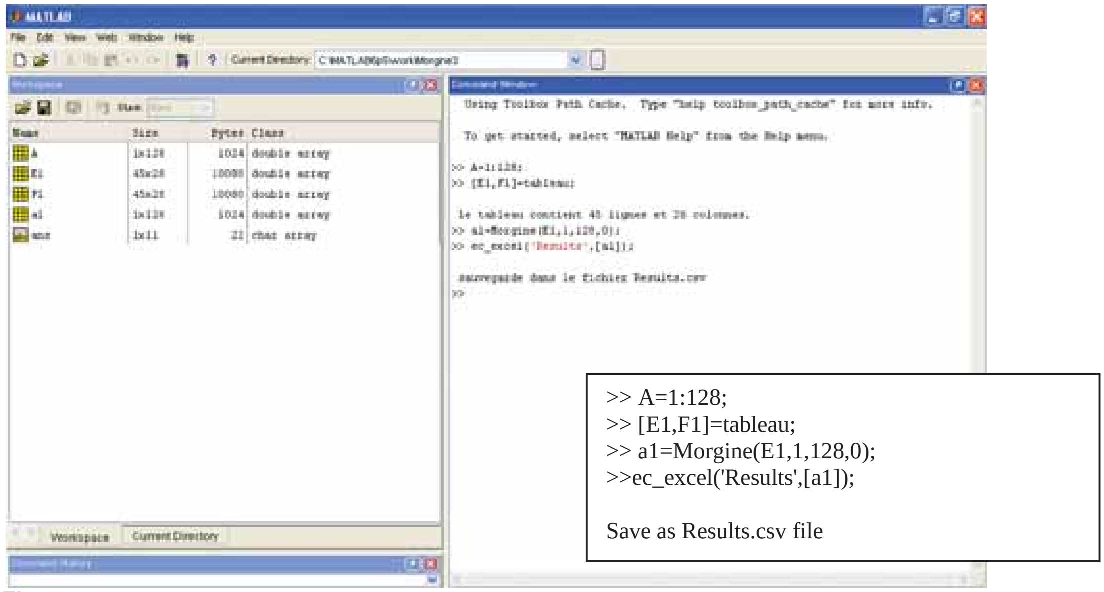


**Figure 7:** Morgine under the Matlab interface. Source: (Author 2014)

## 2.0 RESULTS

### 2.1. DF cartography

The first simulation performed by DF gives us the following results:

• The average daylight factor value of the Kairouan great mosque is 42.54%.

• *For the prayer hall*, we recorded 1.7% as an average daylight factor. The values range from 0 to 6.13%, corresponding to Lux values varying between 0 and 49 Lux. Therefore, middle and low values correspond to the needs of light in a worship place, but we should bear in mind that we chose a case of daylight maximal penetration (all openings are assimilated with holes). The highest values are recorded in the first bay from the gallery side. These values decrease by getting closer to the Qibla wall. The lowest DF value is recorded inside the Mihrab. The distribution of light inside the prayer hall is uniform and corresponds to the division accomplished by naves and bays (Fig. 8 and Fig. 9)

• *For the gallery*, we recorded an average of 13.21%, values vary between 0 and 51%. Light is deeper in the western gallery than the eastern one. This can be explained by the presence of the lateral and transverse arcades in the eastern gallery, formed by a double row of parallel arcades opened into the courtyard.

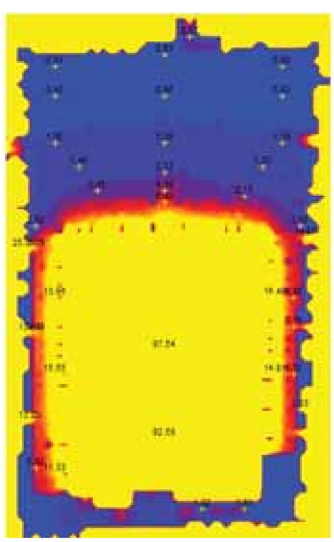

**Figure 8:** DF Cartography of the Kairouan great mosque. Source: (Author 2014)

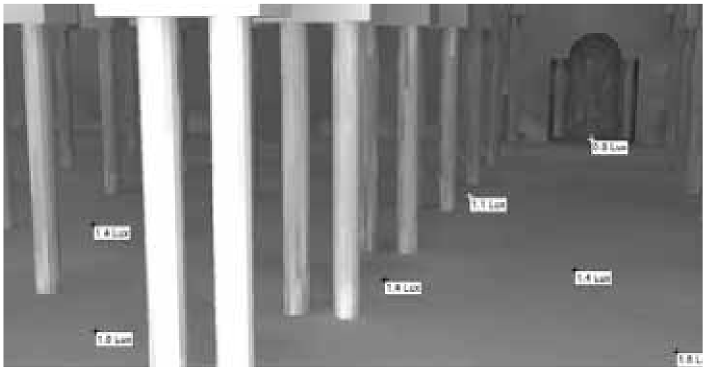

**Figure 9:** Illuminance radiance simulation. Source: (Author 2014)

### 2.2. Form of the DF distribution

To study the form of the DF distribution in the Kairouan great mosque, we applied morphometric steps:

- Exporting the analysis grid with DF values in CSV format (figure10), forming a table, which is in this case made by 45 lines and 28 columns ;
- Generating a morphometric transcription picture (Fig. 11) ;
- Creating a frequency curve of the DF distribution form (Fig. 12).

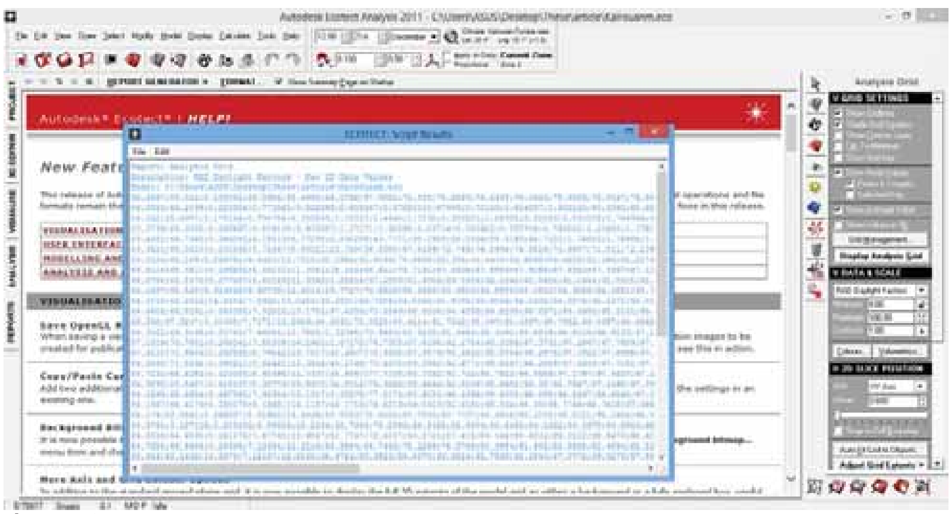

**Figure 10:** Table of values exportation in CSV format. Source: (Author 2014)

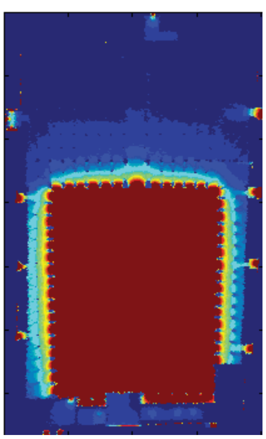

**Figure 11:** Morphometric transcription picture. Source: (Author 2014)

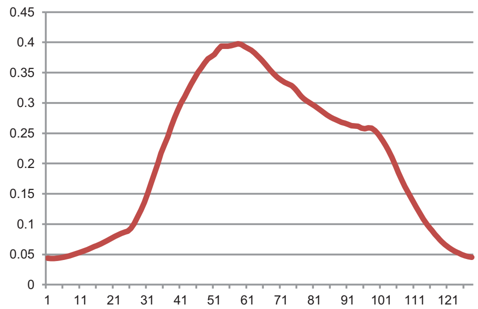


**Figure 12:** Curve of the DF morphometric distribution. Source: (Author 2014)

The curve has a peak which corresponds to the courtyard. It is the main source of natural light distribution inside the prayer hall and the gallery. The amplitude of the curve is directly linked to the proportions of this courtyard.

## CONCLUSION

This paper describes a scientific method for measuring natural light distribution inside constructed buildings. We explained different steps of Morphometric method of the daylight factor through the case of the Kairouan great mosque.

Obtained results confirm that natural light can be considered as a measurable morphological phenomenon. Thus, combining the numerical daylight simulation and the morphometric analyses allows the transformation of sensitive into tangible.

This work shows that the spread of natural light in Kairouan great mosque is directly linked to its form, particularly the form of the courtyard and the galleries that surround it; and that getting closer to the Qibla wall, decreases the amount of natural light. Light is an important element in the conception of mosques.

The results of this simulation inform about the architectural built heritage and contribute to the knowledge of the logic behind the field of morphology correlated with daylight. We plan to apply this approach on a larger corpus formed by Maghreb great mosque with a view to understanding the logic of sustainable development from a built heritage.

## REFERENCES

Saci, Ben A. 2000. Identification des formes, intervention lors du Séminaire : *Concevoir et faire le projet en architecture : analyser, expérimenter et enseigner*, Tunisia.

Bodart, M. 2002. Création d'un outil d'aide aux choix optimisé du vitrage du bâtiment selon des critères physiques économiques et écologiques pour un meilleur confort visuel et thermique. Thesis UCL.

Cauwerts, C. 2013. Influence of presentation modes on visual perceptions of daylit spaces. Thesis UCL.

Dubois, C. 2006. Confort et diversité des ambiances lumineuses en architecture, l'influence de l'éclairage naturel sur les occupants. Thesis GRAP Laval.

Gabrieli, F., *Maghreb Médiéval, l'apogée de la civilisation islamique dans l'occident arabe*, Edisud.

Gallas, Ma. 2013. *De l'intention à la solution architecturale, proposition d'une méthode d'assistance à la prise en compte de la lumière naturelle durant les phases amont de conception*. Thesis Loarraine University.

Marsh J. A. 2007. Radiance and Daylight Factors in Natural Frequency Journal, N°4.

Saladin H., *La mosquée de Sidi Okba à Kairouan*, Ernest Le Roux, Paris, 1899.

Sebag P., *La grande mosquée de Kairouan,* collection Nouvel Observateur, Delpire, 1977.

"Momin Bannani Photos", last modified September, 2014, http://www.flickr.com/photos/mominbannani.

---

[i]The original text in french : "*Je me trouve, une fois de plus, dans la Grande Mosquée de Kairouan, au centre de cette immense cour inondée de lumière. Par la pensée, j'abolis les dalles qui recouvrent régulièrement le sol, le minaret qui s'élance vers le ciel, la salle de prières qui lui fait face et les portiques qui achèvent de fermer l'horizon*".