

**Energy analysis of the envelope of a historic building for its conservation and protection****Análisis energético de la envolvente de un edificio histórico para su conservación y resguardo**

ZAVALA-HERNÁNDEZ Karina†, HERNÁNDEZ-LÓPEZ María Isabel, DEMESA-LÓPEZ Francisco Noé and SERRANO-ARELLANO, Juan\*

*División de Estudios de Posgrado e Investigación, Tecnológico Nacional de México / IT de Pachuca. Carretera México-Pachuca Km. 87.5, Colonia Venta Prieta, Pachuca de Soto, Hgo. C.P. 42080. México.*

ID 1<sup>er</sup> Author: *Karina, Zavala-Hernández* / CVU CONAHCYT ID: 763456

ID 1<sup>er</sup> Co-author: *María Isabel, Hernández-López* / CVU CONAHCYT ID: 789620

ID 2<sup>do</sup> Co-author: *Francisco Noé Demesa-López*, / ORC ID: 0000-0001-7197-6017

ID 3<sup>er</sup> Co-author: *Juan, Serrano-Arellano* / Researcher ID Thomson: F-1060-2013

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**Abstract**

The present investigation exposes the process of energy analysis through the study of lighting in a historical monument located in the City of Pachuca de Soto, Hgo. The objective was to establish a lighting proposal and create a nighttime atmosphere for the main avenue where it is located. The above taking into account energy consumption and the non-affectation of the building. With the analysis of the results, a lighting design was proposed to protect and preserve the original envelope of the historical monument, allowing the construction to be highlighted. In the methodology, the survey plans were made in AutoCad, the virtual model was created in DIALux evo 11, the Taxco Charter, regulations for lighting of historical monuments, was considered. The results obtained the design of the prototype of the already illuminated monument. With this, the number of luminaires was determined and energy savings were achieved without altering the conservation of the city's cultural heritage.

**Lighting, Conservation of Envelopes, Historical Monument**

**Resumen**

La presente investigación expone el proceso del análisis energético a través del estudio de iluminación en un monumento histórico ubicado en la Ciudad de Pachuca de Soto, Hgo. El objetivo fue de establecer una propuesta de iluminación y crear un ambiente nocturno para la avenida principal donde se encuentra. Lo anterior tomando en cuenta el consumo de energía y la no afectación del edificio. Con el análisis de los resultados se propuso un diseño de iluminación para proteger y conservar la envolvente original del monumento histórico, permitiendo a su vez resaltar la construcción. En la metodología se realizaron los planos del levantamiento en AutoCad, se creó la maqueta virtual en DIALux evo 11, se consideró la Carta de Taxco, normativa para iluminación de monumentos históricos. En los resultados se obtuvo el diseño del prototipo del monumento ya iluminado. Con esto se determinó la cantidad de luminarias y se logró un ahorro energético sin alterar la conservación de un patrimonio cultural de la ciudad.

**Iluminación, Conservación de Envolventes, Monumento Histórico**

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\* Correspondence to Author (e-mail: [juan.sa@pachuca.tecnm.mx](mailto:juan.sa@pachuca.tecnm.mx))

† Researcher contributing as first author.

## 1. Introduction

Architecture is the process of a diagnosis, an analysis, a synthesis and thus reach the development of a proposed project, it is designed in an aesthetic and functional way with the purpose of satisfying the needs of the human being. Nowadays when creating spaces it is required not only a functional design but also all the observable elements of the facade, roof and foundation, being a factor of utmost importance to create and design buildings or monuments is to use an analysis in relation to natural lighting, but sometimes due to the location and natural factors the lighting provided by the sun is not enough, Likewise, at night there is a lack of light, so great importance is given to artificial lighting, with a good lighting design it is possible to denote shapes, objects and details, by manipulating the lighting you can highlight certain points and achieve a transformation in the way of visualizing the buildings, creating effects and sensations in the viewers.

In architecture, is where there is a closer relationship between art and light, since the latter, unlike what happens in other arts, is not only the agent of communication between the work and the viewer, but is part of the same artistic creation by modeling, with a play of light and shadows, its plastic forms and enhance the materials used in its construction [1].

In the present study an energetic analysis was carried out through the study of lighting in a historical monument: the Basilica Menor de Nuestra Señora de Guadalupe "la villita", located in Pachuca de Soto, Hidalgo, Mexico with the objective of proposing a lighting design to protect and conserve the original envelope of the historical monument, allowing in turn to highlight the construction.

## 2. Theoretical Framework

The facades play a crucial role in the architectural envelope, since they constitute the visible face of the building. Throughout the history of architecture, they have been interpreted in various ways. Both their surface and their design are influenced by the function of the building, the materials used, the location, the climate, the prevailing historical or artistic movements, as well as the sensibilities of the owner or architect.

In addition to their practical function, facades contribute to defining the character of the building and fulfill various functions, whether formal, aesthetic or symbolic, thus reflecting the social and economic needs of the context in which they are located.

Lighting technology, placed at the service of aesthetics, plays today a primordial role in the plastic arts, and, specifically, the illumination of facades and monuments makes it possible to recreate, at night, their architecture and achieve results of great beauty that may even be superior to those obtained with daylight, but which, in any case, if the lighting harmonizes with their forms and atmosphere, will provide the delicate pleasure of discovering a new and surprising beauty, different from that obtained under sunlight, but no less interesting. So man has sought to illuminate his architectural works to enhance and magnify them. [1]

According to the National Commission for the Efficient Use of Energy (CONUEE), best practices in envelope design and lighting can save at least 40 percent of a building's total energy use, while bad practices can increase it by up to 90 percent.

Lighting can manage the work and colors that can be generated, as well as the saturation and contrasts that are needed to create a correct lighting design, in the same way art is created. Lighting in historic buildings is regulated through the Taxco Charter, a regulation to regulate proposals on nighttime lighting of monuments and historic centers with the aim of contributing to the conservation, safeguarding and enhancement of cultural heritage from different approaches. [3]

### 2.1. General lighting criteria for historic monuments

The development of lighting projects in monuments and historic centers should contain the following sections:

Research. Historical, graphic, photographic and documentary information, which allows a deep knowledge of the property and the place; for this it will require the bibliographic consultation, of historical, photographic or cartographic archives.

This documentation will allow a more precise analysis of the conditions of the object to be intervened; it will also be a fundamental basis for the conceptual proposal to be developed to be developed. [2]

Conceptual proposal of the intervention. It will rigorously describe the characteristics of the building or the historic zone; its movable assets, relevant architectural or natural elements; its formal, stylistic, urban and architectural characteristics; its reading with natural lighting, considering the environment inside and outside the building and its relationship with its immediate surroundings; in the same way if it is a public space; the type and location of the primary and secondary light sources should be analyzed, and if necessary, the type and location of the primary and secondary light sources should be analyzed, as well as its relationship with its immediate surroundings; in the same way if it is a public space, the type and location of the primary and secondary light sources should be analyzed and secondary light sources and, if applicable, orientation and solar incidence.

In this section we must clarify the objective of the intervention; function, type, levels and contrasts of illumination; means of the means to achieve it, technical characteristics, fixing systems, location of the luminaires, orientation and solar incidence location of the luminaires and the electrical power distribution network and their specifications (degree of safety); especially the environmental impact study impact on the environment.

Development of the proposal. Lighting tests will be carried out in order to verify the hypothesis of the proposal, after the hypothesis of the proposal, prior authorization of the pertinent instances for its execution.

## **2.2. Interior and exterior lighting**

### **Interior lighting**

- Light sources should not emit light radiation, particularly in the ultraviolet (100nm - 380nm1) and infrared (780nm - 1nm) range.

- The lighting concept must respect and take into account the architectural space and the vocation of the building.
- The equipment to be installed should be of small dimensions, with a simple, contemporary and high efficiency design.
- The light must reproduce the existing colors correctly, without creating false reproductions through the use of different color temperatures, i.e. using colored lights.
- No equipment or wiring should be installed on artistic elements.
- It is strictly forbidden to drill holes or anchor in ornamental areas such as reliefs, sculptures, mural paintings, coffered ceilings, altarpieces, etc., as well as structural elements in a poor state of conservation.
- Consider the easy maintenance of the proposed system.

### **Outdoor lighting**

- Identification and analysis of the characteristics of the historic building and its surroundings.
- The proposed project should provide the building with UNIFORM lighting that allows the UNITY of the work to be appreciated and avoids its distorted and fragmented appreciation.
- The monument should be emphasized in relation to its surroundings, without excessive contrast, which would trigger competition, i.e., an escalation of light.
- The concept of the project should observe a lighting system free of the building.

- Avoid placing luminaires on the facade that require drilling or drilling any element of stone, wood, etc., in any part of the building. If it is necessary to place luminaires and wiring on roofs, decks, towers, etc., other methods of fixing the different components of the lighting system may be used.
- Drilling or anchoring in ornamental areas such as reliefs, sculptures, mural paintings, coffered ceilings, altarpieces, etc., as well as structural elements in a poor state of conservation, is strictly prohibited.
- Floor lamps should be avoided, since they distort the reading of the buildings by inverting shadows and cause glare to pedestrians.
- Whatever the method of fixing and the location of wiring, electrical equipment, lighting fixtures, etc., must be detailed in the project by means of plans, diagrams, etc., which must be supervised by a qualified professional. The project must be supervised by a competent technician and approved by the appropriate authorities.
- Artificial lighting projects should avoid the residual effect known as light pollution, whereby a large part of the light is emitted into the night sky.
- The installation must be designed in such a way that the location and access to the different components allow for easy maintenance of the system, especially for lamp replacement, equipment cleaning, etc
- The project must include a maintenance manual where the maintenance tasks are programmed according to the useful life hours of the proposed lamps and precise instructions for their replacement, handling of luminaires, and any other tasks necessary for the correct operation of the system.

- The lighting system and its electrical components must be strictly adapted to the official safety regulations on electrical installations.

### 3. Methodology

It began with site reconnaissance, research and identification of materials and construction system, survey and architectural plans, virtual model and lighting study of the Basilica Menor de Nuestra Señora de Guadalupe "la villita", located in Pachuca de Soto, Hidalgo, Mexico. [2]



**Figure 1** Minor Basilica of Our Lady of Guadalupe. Image taken on 07/04/2023

Source.:

<https://mx.infoaboutcompanies.com/Catalog/HGO/Pachuca-deSoto/Iglesia-catolica/Bas%C3%ADlica-de-Santa-Mar%C3%ADA-de-Guadalupe>



**Figure 2** Volumetric model of the Basílica Menor de Nuestra Señora de Guadalupe. Image extracted on 07/04/2023

Source:

<https://www.muvipa.com.mx/eventos/dia-mundial-del-turismo/>

Analysis of the materials used in the construction [5] to obtain their reflection coefficients, Table 1. This is done on the main façade and also on the side façade, which are the ones that are visible to people and to which the required lighting design will be made.

Minor Basilica of Our Lady of Guadalupe		
Surface	Materials	Reflection Coefficient (%)
Main facade	White quarry stone in blocks of 60x38 cm	White color Stone 0.75-0.85 Stone 0.30
	Wooden door	0.10-0.25
	Stainless Steel blacksmith	0.5
Side facade	White quarry stone in blocks of 60x38 cm	White color Stone 0.75-0.85 Stone 0.30
	Asymmetrical quarry stone in cold colors	Cold colors Stone 0.10-0.20 Stone 0.30
	Wooden door	0.10-0.25
	Stained glass	1.50-1.66

**Table 1** Table of materials for facade finishes

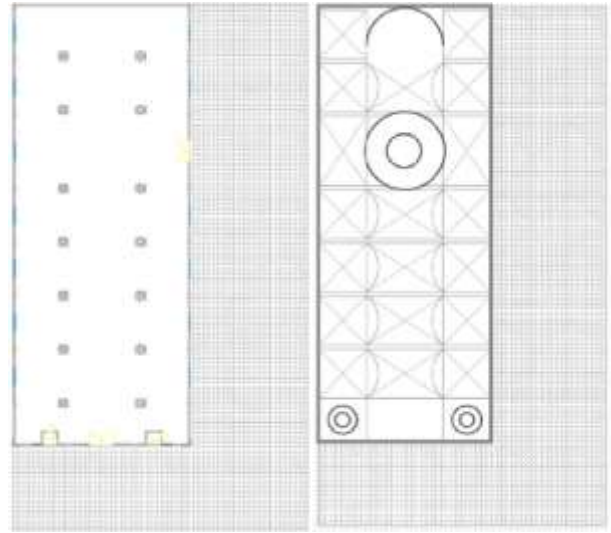


**Figure 3** Main façade of the Basílica Menor de Nuestra Señora de Guadalupe, Pachuca, Hgo.  
Source: Own Elaboration

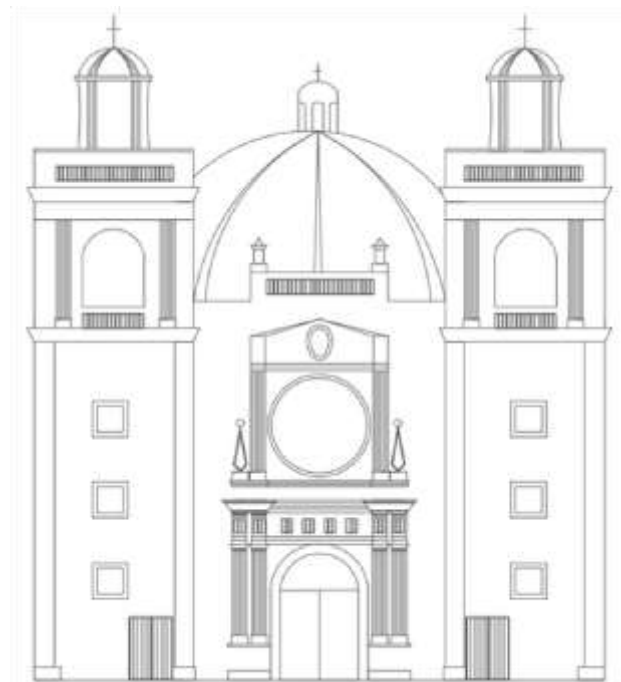
As can be seen, the building has white quarry stone envelopes, stained glass in the windows and wooden doors. [4]

### 3.1. Architectural Survey

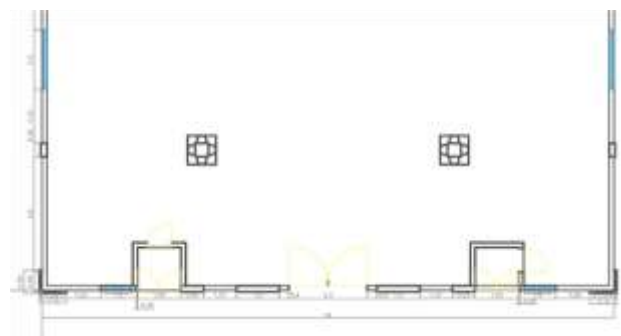
The architectural survey of the Basílica Menor de Nuestra Señora de Guadalupe, in Pachuca de Soto, Hgo. was carried out, and the necessary measures were established to obtain the results for energy efficiency and cost savings through an adequate distribution of lighting. The data was transferred to the AutoCAD program to generate the architectural plan to be identified in the study area plan. Figure 3 shows the architectural plans of the Basilica.



**Figure 4, 5** Architectural plan and overall plan of the nave of the Basilica  
Source: Own Elaboration



**Figurer 6** Main façade of the Minor Basilica of Our Lady of Guadalupe  
Source: Own Elaboration

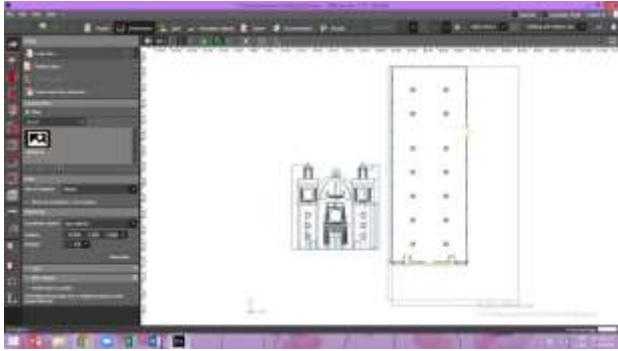


**Figure 7** Measurements of the main façade of the Basilica of Our Lady of Guadalupe  
Source: Own Elaboration



### 3.2. Architectural modeling

The DWG file is imported into the DIALux program where the modeling of the Basilica and the design of the luminaire will be done in order to perform the necessary calculations.



**Figure 8** DWG file imported to the DIALux program of the ground plan and the main façade of the Basilica  
*Source: Own Elaboration*

The 3D model of the Basilica is obtained, where the main and lateral facades can be observed, as well as the atrium and the lateral patio of the basilica, which is where the calculation of the luminaire will be made, seeking to give a more realistic result of the lighting design that was planned for the monument.



**Figure 9** 3D modeling of the minor Basilica of Our Lady of Guadalupe, "La Villita", elaborated with the DIALux program  
*Source: Own Elaboration*

This time the facades will be illuminated and this type of lighting will be: diffuse, focused, framed, indirect or direct, in order to enhance specific areas of the monument in this case, as well as its ornamentation, columns, bell towers, stained glass, among others.

Likewise, a lighting design was made in the atrium, which is the patio in front of the main façade and also the side patio of the Basilica, neither of the two patios is for pedestrian circulation, however they work for it, but due to the analysis there is very little pedestrian circulation in them, except for the days of celebration of the Virgin of Guadalupe.

Therefore, they do not require a great lighting, only of the access to the Basilica, in this way a greater amount of luminaire is taken in the access, trying to reach the 20lux that are the ideal for pedestrian passage, but the main design of the Basilica is to enhance the monument, so the focus is based on the facades. According to the observations made, the church already has lighting that consists of a few light poles that are turned on approximately from 7:00 p.m. to 10:00 p.m. and lamps on the roof overlooking the side façade (these are only turned on on holidays), leaving the monument without lighting. [6]

### 4. Preliminary results

The lighting proposal for the Basilica aims to give a new approach, trying to promote a night city awake, enhancing this construction through its lighting, this new design is based on making approaches in the construction lacquer through a diffuse lighting, creating grandeur in the monument. The following render shows the lighting design of the facade and atrium.



**Figure 10** Rendering of the main facade of the proposed luminaire of the Basílica Menor de Nuestra Señora de Guadalupe, "La Villita".  
*Source: Own Elaboration*



**Figure 11** Rendering of the lateral façade of the proposed luminaire of the Basílica Menor de Nuestra Señora de Guadalupe, "La Villita", elaborated with the DIALux program

Source: Own Elaboration

Product data sheet

LOGIC LINEAR B8C WALL GRABRAG 830 DIM5

Parameter	Value	Unit	Min	Max
Power	33.0	W	0	33.0
Beam diameter	1561	mm	0	1561
Beam angle	60	°	0	60
Beam diameter at 1m	1561	mm	0	1561
Beam diameter at 2m	3122	mm	0	3122
Beam diameter at 3m	4683	mm	0	4683
Beam diameter at 4m	6244	mm	0	6244
Beam diameter at 5m	7805	mm	0	7805
Beam diameter at 6m	9366	mm	0	9366
Beam diameter at 7m	10927	mm	0	10927
Beam diameter at 8m	12488	mm	0	12488
Beam diameter at 9m	14049	mm	0	14049
Beam diameter at 10m	15610	mm	0	15610

TERRA EDLSTEIN 130

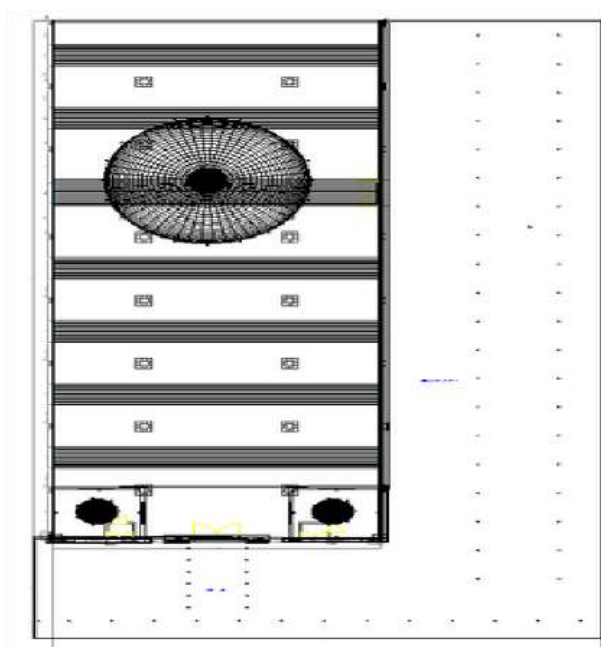
Parameter	Value	Unit	Min	Max
Power	4.0	W	0	4.0
Beam diameter	328	mm	0	328
Beam angle	60	°	0	60
Beam diameter at 1m	328	mm	0	328
Beam diameter at 2m	656	mm	0	656
Beam diameter at 3m	984	mm	0	984
Beam diameter at 4m	1312	mm	0	1312
Beam diameter at 5m	1640	mm	0	1640
Beam diameter at 6m	1968	mm	0	1968
Beam diameter at 7m	2296	mm	0	2296
Beam diameter at 8m	2624	mm	0	2624
Beam diameter at 9m	2952	mm	0	2952
Beam diameter at 10m	3280	mm	0	3280

WE-EF

Parameter	Value	Unit	Min	Max
Power	27.0	W	0	27.0
Beam diameter	1081	mm	0	1081
Beam angle	60	°	0	60
Beam diameter at 1m	1081	mm	0	1081
Beam diameter at 2m	2162	mm	0	2162
Beam diameter at 3m	3243	mm	0	3243
Beam diameter at 4m	4324	mm	0	4324
Beam diameter at 5m	5405	mm	0	5405
Beam diameter at 6m	6486	mm	0	6486
Beam diameter at 7m	7567	mm	0	7567
Beam diameter at 8m	8648	mm	0	8648
Beam diameter at 9m	9729	mm	0	9729
Beam diameter at 10m	10810	mm	0	10810

**Table 2** Images with description of the luminaire to be used in the project. Prepared with the DIALux program

Source: Own Elaboration



**Figure 12** Architectural plan of the proposed luminaire of the Basílica menor de nuestra señora de Guadalupe, "La Villita", elaborated with the DIALux program

Source: Own Elaboration

### 5. Lighting design proposal

Luminaires used in the project: it is intended to use 3 types of luminaires for the lighting design of the Basilica, 2 for the floor and one for the ceiling, determining that they are suitable for the project. According to the descriptions in Table 2 and 3.

Luminaire list

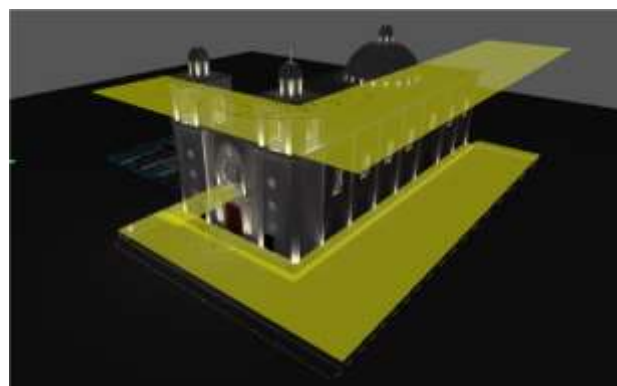
Qty	Power	Luminous efficacy
15767	105.0 W	51.6 lm/W

Qty	Manufacturer	Article No.	Article name	P	Ø	Luminous efficacy
23	Delta Light	30824 9365	LOGIC LINEAR B8C WALL GRABRAG 830 DIM5	33.0 W	1561 mm	47.3 lm/W
112	RZE	641342.00	TERRA EDLSTEIN 130	4.0 W	328 mm	80.8 lm/W
24	WE-EF	630-382	DOC120 (N) IP66 LED FT 30W/3K + 30-180°	27.0 W	1081 mm	37.1 lm/W

**Table 3** Description of the luminaires to be used in the project. Prepared with the DIALux program.

Source: Own Elaboration

Figures 12 and 13 show the 3D modeling of the useful plane and false colors in DUALux.

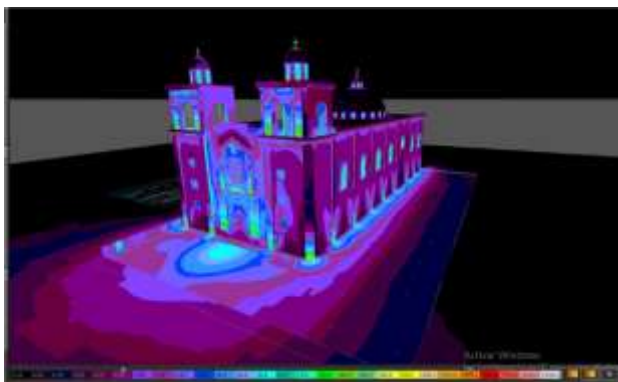


**Figure 12** 3D model of the minor Basilica of Our Lady of Guadalupe, "La Villita", showing the useful plan, elaborated with the program DIALux

Source: Own Elaboration

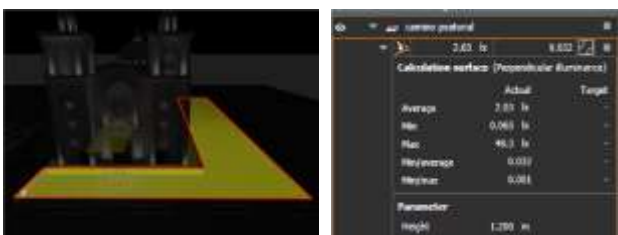
The yellow layer is the useful plane, which is the level where DUALux is measuring the illumination, the black lines are the isolines which is the light distribution in a plane.

The false colors, these work as a thermal camera, it tells you 100° red color 50° orange color, in blue color 0, the false colors work similar but instead of telling you the heat level they tell you the illumination level, you can see the amount of luxes according to the lower bar in the following image and you can see, as only some areas of the monument are highlighted and as in the access there is more light, the maximum required for the entrance is 20lux and you can see that if it complies with what was proposed.

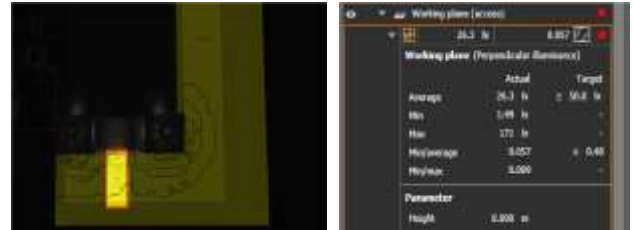


**Figure 13** 3D modeling of the minor Basilica of Our Lady of Guadalupe, "La Villita", where the false colors are shown, elaborated with the DIALux program  
 Source: Own Elaboration

Figures 14, 15 and 16 show the lighting results and the amount of lux used in the area. For the access to the Basilica the lighting that is functional and required is 20 lux minimum, and for the conservation of the enclosure, the lighting should not affect the material and its surroundings.

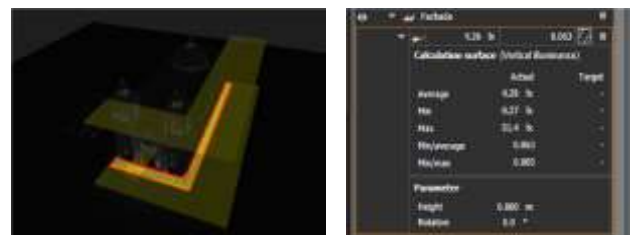


**Figure 14** 3D modeling of the Basilica Menor de Nuestra Señora de Guadalupe, "La Villita" with the amount of lux used in the area outlined in red  
 Source: Own Elaboration



**Figure 15** 3D modeling of the Basílica Menor de Nuestra Señora de Guadalupe, "La Villita" and amount of luxes used in the area outlined in red, Elaborated with the DIALux program  
 Source: Own Elaboration

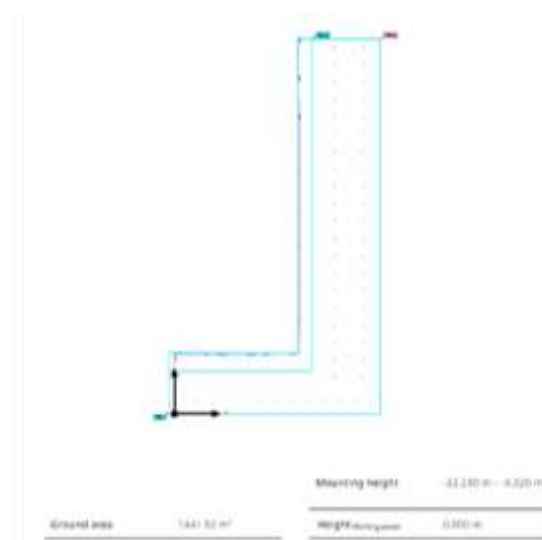
This area shows the main access, where a greater number of luminaires is proposed, resulting in an amount of 26.3 lx, exceeding the minimum amount of 20 lx required for a crosswalk.



**Figure 16** 3D modeling of the Basilica Menor de Nuestra Señora de Guadalupe, "La Villita" and amount of lux used in the area outlined in red  
 Source: Own Elaboration

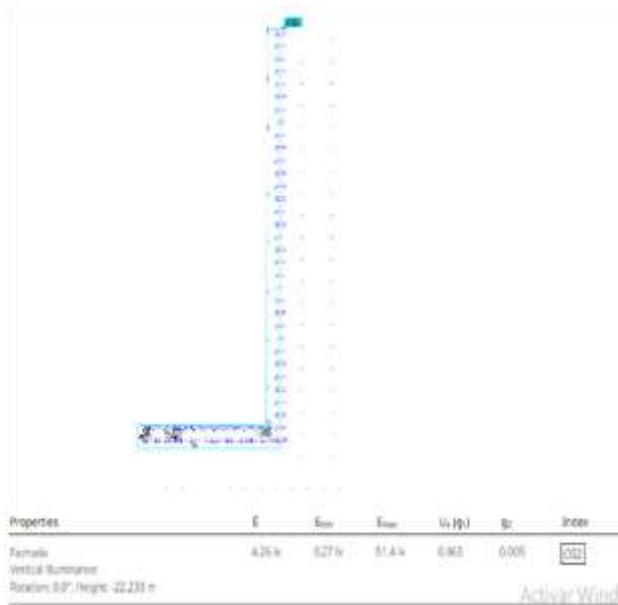
Figure 16 shows some of the luminaires of the main columns, resulting in an amount of 4.26 lx.

Figures 17, 18 and 19 show the plans of the placement of the luminaires in the atrium and lateral façade of the Basilica Menor de Nuestra Señora de Guadalupe.



**Figure 17** Plan of luminaries of the Basílica Menor de Nuestra Señora de Guadalupe, "La Villita"  
 Source: Own Elaboration





**Figure 18** Plan of luminaires of the Basilica Menor de Nuestra Señora de Guadalupe, "La Villita"  
 Source: Own Elaboration



**Figure 19** Results DIALux evo11, atrium and side façade luminaires  
 Source: Own Elaboration

**6. Conclusions**

The envelope of a building is of utmost importance as it protects from the weather and is the finish that highlights the building, highlighting that the design of a building to be energy efficient, have to consider different aspects among which are: climate identification, location to promote ventilation and natural lighting, construction materials and activity to be developed within the building.

Being every day of utmost importance the analysis of lighting in buildings, as well as historical monuments, to determine efficiently the number of luminaires that allow energy efficiency. Thus, the building under study, when determined as a historical monument, must be protected, preserved with adequate lighting that does not affect the envelope of its construction, thus highlighting the monument, being attractive to the public, favoring tourism in the city.

The perspective of the landscaping changes completely, the objective of attracting the public is fulfilled correctly, creating a more attractive place, so it is proposed that the project is feasible to carry out.

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