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Journal of Architecture and Design

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Support the International Scientific Community in its written production of Science, Technology in Innovation in the Humanities and Behavioral Sciences Area, in the Sub-disciplines of international architecture, technological innovation in architecture, industrial design, business design techniques, multimedia design, advertising design, web system design, residential architecture.

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Knowledge Area

The works must be unpublished and refer to issues of international architecture, technological innovation in architecture, industrial design, business design techniques, multimedia design, advertising design, web system design, residential architecture and other topics related to Engineering Sciences and Technology.

Presentation of the Content

In Issue 18, is presented an article *Thermographic analysis and influence of colour on the temperature of building materials in a warm sub-humid climate*, by ZAPATA-PADILLA, Néstor Juan & GÓMEZ-PEDRAZA, Carlos, with adscription at Universidad Autónoma de San Luis Potosí, in the next article we present, *Waterproofing materials used in buildings in the colonial period in Mexico: Case study Huichapan, Hidalgo* by RODRÍGUEZ-URIBE, Juan Carlos, TREJO-TORRES, Zaira Betzabeth and BENÍTEZ-ALONSO, Margarita, with adscription at Tecnológico Nacional de México/Instituto Tecnológico Superior de Huichapan, in the next article we present, *Energy analysis of the envelope of a historic building for its conservation and protection* by ZAVALA-HERNÁNDEZ Karina, HERNÁNDEZ-LÓPEZ María Isabel, DEMESA-LÓPEZ Francisco Noé and SERRANO-ARELLANO, Juan, with adscription at Tecnológico Nacional de México / IT de Pachuca, in the next article we present, *Redesign of Roads for the optimization of Urban Space, integrating a Sustainable Mobility* by BENITEZ-ALONSO, Margarita, FLORES-CORTES, Herminio, TREJO-TORRES, Zaira Betzabeth and RODRIGUEZ-URIBE, Juan Carlos, with adscription at Tecnológico Nacional de México / Instituto Tecnológico Superior de Huichapan.

Content

Article **Journal Architecture and Design**
December, 2023 Vol.7 No.18 1-9

Thermographic analysis and influence of colour on the temperature of building materials in a warm sub-humid climate

Análisis termográfico y la influencia del color en la temperatura de los materiales de construcción en un clima cálido subhúmedo

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Abstract

This work presents the results of the research carried out in the Bachelor of Architecture of the FEPZH; research that was also presented in the event of the 29th edition of the summer of science of the UASLP, and deals with the fluctuation in the balance of thermal comfort that can cause the color of the constructive elements; It analyses the oscillation and differences in the temperature of the different walls built with block of different thicknesses; 10cm, 12cm, 15cm, and 20cm; in order to obtain objective information to be able to recommend the range of colors for the sub-humid quality zone, such as Ciudad Valles, and thus support the decision making of urban planners and professionals who are dedicated to architectural design. In June 2023, the nine objects of study were built; walls with a surface area of one square meter, to which paints of different shades were applied, and subsequently the temperatures were recorded with the help of measuring equipment obtained thanks to the support of PRODEP.

Comfort, Temperature, Color walls

Resumen

Este trabajo presenta resultados de la investigación que se realiza en la Licenciatura de Arquitectura de la FEPZH, para el evento de la 29a edición del verano de la ciencia de la UASLP, y trata sobre el confort térmico generado por el color de los elementos constructivos; se analiza la oscilación y diferencias de la temperatura que originan los distintos colores aplicados en los muros construidos a base de block en distintos espesores; 10cm, 12cm, 15cm, y 20cm; con el fin de obtener información objetiva para poder recomendar la gama de colores para la zona calidad subhúmeda, como lo es Ciudad Valles, y así apoyar a la toma de decisiones de los urbanistas y profesionistas que se dedican al diseño arquitectónico. En el mes de junio del año 2023 se construyen los nueve objetos de estudio; muros de una superficie de un metro cuadrado; a los que se les aplican pinturas de distintas tonalidades y posteriormente se registran las temperaturas con ayuda de equipos de medición que se obtuvieron gracias al apoyo del PRODEP.

Confort, Temperatura, Muros de color

Citation: ZAPATA-PADILLA, Néstor Juan & GÓMEZ-PEDRAZA, Carlos. Thermographic analysis and influence of colour on the temperature of building materials in a warm sub-humid climate. Journal Architecture and Design. 2023. 7-18: 1-9

† Researcher contributing as first author.

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December 2023 Vol.7 No.18 1-9

Introduction

It is common to find manufactured environments that are worse than the natural environment. This contrasts with the role of architecture and urban planning to provide a corrected environment according to the individual's needs. New architecture and good urban planning must necessarily relate to man, architecture, and climate, achieving a conciliation between them (Álvarez, 2004).

Ciudad Valles, San Luis Potosí is located at the geographical coordinate 21°59′ 12″N 99°01′ 07″W, located at 85 masl on average, it has a warm sub-humid AW0 climate with a considerable relative humidity of 78% due to the influence of hydrology and the vegetation that abounds due to the proximity to the Sierra Madre Oriental, the average temperature is 24. 7°C; minimum of 6°C and maximum of 47°C according to SMN-CONAGUA information; and according to City newspapers; with maximums of up to 56°C with a thermal sensation of 60°C; wind speed is 6km/hr.

Color	Period	Hours	Recommendations
Red	May to September	11:00 to 19:00	Control of solar radiation, relative humidity and radiant temperature. Mechanical ventilation is required..
Orange	April	13:00 to15:00	Control of solar radiation and radiant temperature. Generate wind.
Yellow	March to November	24 hours	Decrease relative humidity, radiant temperature and daytime solar radiation.
Gray	Dicember to January	11:00 to 17:00	No intervention necessary as long as there are solar obstructions.
Gray	February	10:00 to 13:00	No intervention necessary as long as there are solar obstructions.
Blue	November, Dicember, January, and February	Before 10:00 and after 18:00	Decrease wind and increase radiant temperature.
Purple	January, February and Dicember	3:00 to 8:00	Increase radiant temperature.

Table 1 Bioclimatic recommendations for Ciudad Valles *(Zapata, 2021)*

As shown in table 1, Ciudad Valles has an unfavorable climate during most of the year and most of the hours of the day, so it is anticipated that a good thermal performance of the materials is necessary to cushion the climatic effects that affect the indoor environment of the dwellings and the outdoor urban spaces.

Thermal comfort in dwellings is the hydrothermal perception that people have of the interior of the spaces they inhabit. The definition of this term is inspired by the achievement of harmony between temperature and relative humidity. This concept implies that the people living in the dwellings perceive a neutral thermal sensation. In other words, the atmosphere they experience is neither hot nor cold. It is the perfect point for there to be a temperature balance without the need for people to sweat. Thermal comfort in dwellings is of vital importance because discomfort caused by inadequate temperature can affect people's health. However, it is not only used to evaluate the quality of the environment in a house, but also for spaces with other uses, such as outdoor spaces.

Color and temperature have a curious physical relationship and, as such, can be explained by science. This determines, for example, which colors absorb heat and which repel it. Thermal energy obeys the same conservation laws as light energy. This is the key that reveals the secrets of binomial color and temperature. If a given substance reflects most of the wavelengths of light, it will also reflect most of the thermal energy. Therefore, because of the visible nature of the light spectrum, colors that reflect most wavelengths of light tend to be cooler than those that reflect only a few wavelengths. In other words, colors that reflect more lighter repel more heat.

Heat is a form of energy that is spontaneously transferred between different areas of the body or from one body to another. Heat and temperature are different things, although they are closely related. Heat is the transfer of thermal energy from a body of higher temperature to a body of lower temperature. Temperature, on the other hand, is the physical quantity that measures the thermal state of a body and the kinetic energy of its molecules.

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Objective

In the present research, the objective is to record the temperature of the block walls over a period of three months, to analyze with the support of graphs produced in Excel, the oscillation and temperature differences that are generated on the surfaces of the construction elements due to the different colors; and with the support of the comfort ex application, the balance of thermal comfort of the person is calculated, by entering the different temperature values recorded. With this we intend to simulate the impact that the colors applied on the walls have on the thermal comfort of the person. The objects of study are nine walls built with blocks of different thicknesses; 10cm, 12cm, 15cm and 20cm, covered with vinyl paint in the following colors: white, cream, lime green, orange, blue, gray, brown, dark green and black.

Objectives

As particular objectives, in addition to carrying out a documentary analysis of the literature on the subject and integrating a photographic file, the specific objectives of the research are as follows: to construct the nine objects of study, record the temperatures of the walls, take pictures with the thermographic camera, and once the data is obtained, a database is created in Excel to organize it and obtain comparative graphs to analyze the results. In addition to Excel, the comfort ex application is used to calculate the thermal comfort balance by adjusting the temperature of the walls to identify the variation generated by each color.

Hypothesis

The hypothesis behind this research is that the colors used and the thickness of the block influence the sensation of thermal comfort in urban and architectural spaces, and particularly the temperature of the construction elements themselves. To date, there is no record of similar research for the warm subhumid zone, specifically in Ciudad Valles, San Luis Potosí, so that the temperature variation between different colors such as black and white can be up to 5ºC, and grey vs. white can be 3ºC.

This is according to previous activities and assumptions made by the research group formed by the students of the subject Sustainable Living Spaces, of the seventh semester of the Bachelor of Architecture of the FEPZH of the UASLP, also directed by the advisor of the present research.

Problematic

The strong sun exposure in the city, as well as the prolonged time of sun exposure, causes buildings to heat up and therefore creates uncomfortable environments for people in indoor and outdoor spaces, which reduces the quality of life in the city. This also causes people to avoid walking outdoors during the day, thus, businesses are also affected during the day. Ciudad Valles is gradually becoming a tourist city, therefore, it is important to provide comfortable urban spaces for people visiting the city.

The building regulations do not specify a relevant color range of urban spaces, or construction projects, therefore, many buildings use dark colors, which are believed to increase the air temperature in outdoor spaces. The regulation identifies the need to adapt buildings to the context, however, in most cases, it is interpreted only as giving the same architectural language to buildings in the same area; a visually similar design to neighboring buildings to make the urban area look homogeneous.

Justification

It is considered that this research helps to have objective evidence of temperature variations and excessive heating caused by the colors applied in the constructive elements such as walls; with which the specialized personnel in the different disciplines that deal with urban interventions, as well as the authorities in charge of updating construction regulations and generating urban improvement projects, will be convinced to add particular specifications such as the use of appropriate colors according to the climate of the region.

ISSN 2531-2162

In addition to the above, it is considered that it is possible to improve the urban environment, because by buffering the climatic and environmental conditions of the region; outdoor spaces become more friendly areas for pedestrians and tourists, which can lead to greater social, pedestrian and of course commercial movement in the downtown area; likewise, it would improve the hygrothermal environment inside the family home by reducing the interior heat.

Approach

The research has a mixed approach, since we use measurement equipment, hard data, and thermal comfort, balance calculations with the help of software; with which it is possible to understand and describe the causes and consequences of the physical environmental factors in the context of the construction elements and of course on people's sensations.

Theoretical framework and Methodology

As a theoretical framework, the research is based on the studies and procedures of Ochoa de la Torre, Olgyay, Givoni and the research advisor; where from hard data it is possible to generate graphs and calculations where the physiological characteristics of the constructive, environmental, physical and subjective elements influence to determine the effects on the balance of thermal comfort of the person.

An example of this is the methodology used for the research study “Análisis de la evolución del confort en la vivienda en serie en Ciudad Valles, S.L.P.” and the article “Comfort's evolution analysis of low-cost housing in Ciudad Valles, S.L. P” published in the year 2021, where the microclimatic variables within six social housing units are compiled during one year and then psychometric graphs are used to verify if the interior environments of the houses are comfortable or not. Based on this analysis, it is possible to show some of the climatic and constructive causes that provoke discomfort conditions.

Methodology

Bibliographic research is conducted, and the climatological normal of the city is verified to verify the climate of the region and especially the ambient temperature, which shows that the city is extremely hot. In June 2023, the objects of study were built with the help of the research group formed by the students of the sustainable living spaces course. These walls were made of 10 cm, 12 cm, 15 cm, and 20 cm thick cement blocks.

For the placement of the walls, a 25 cm deep trench was dug where a 20x25 cm cross-section concrete ditch was built, reinforced with stainless steel. Once the concrete had set, the block walls were placed on these ditches with the help of a hand level, a plumb line, and a mason's spoon. The mortar used for the block jointing was of a 1:3 ratio (one portion of cement to three portions of sand), and the thickness of the jointing was 1 cm. Once the mortar dries, the vinyl paint is applied to the walls. Once the elements are finished, they are painted with different shades of color.

Figure 1 Wall construction
Source: Own Elaboration

According to the research on thermal comfort in Ciudad Valles, it was decided to monitor the temperature of the walls at 9:00 h, 11:00 h, 13:00 h, 15:00 h and 17:00 h, since these hours cover the periods of the day when people feel the hottest in the city.

Figure 2 Coating 11:00h
Source: Own Elaboration

ISSN 2531-2162

The consultant organizes a training session on how to use the following measuring equipment: Milwaukee thermographic camera model 2257-20, which is used to take pictures in a range of colors ranging from blue to red, which indicate the temperature of the material in degrees Celsius; Steren infrared thermometers model HER-427 are used to measure the temperature of the surface of the walls in degrees Celsius; the pocket weather station Kestrel model 3500, is used to measure the air temperature in degrees Celsius, the percentage of relative humidity of the air %H. R., and also records wind speed in kilometers per hour or meters per second; and finally, Steren HER-408 lux meters are also used to measure light intensity in lux.

A database is designed with a format to record all measurements, so that when they are captured, the graphs are automatically generated. This is achieved with the help of training in the use of the Excel program.

After having organized the cabinet and research work, as well as having the walls built with the paint already dry, we proceeded to start the temperature measurements to record them and then capture them in the computer.

Figure 3 Measurements 9:00h
Source: Own Elaboration

With the luxmeters, the illumination is recorded to show that all the walls receive an average amount of light, therefore, they are in the same light conditions.

Figure 4 Example of luxmeter recordings
Source: Own Elaboration

Using the thermographic camera, temperature differences can be distinguished in a range of colors. This makes it possible to analyze oscillations and larger differences in wall temperature.

Figure 5 Example of images taken with a thermal imaging camera
Source: Own Elaboration

After having the record of the weeks, we now proceed to work on the application Confort - Ex; where the first exercises are done, which in this case were only six, since the intention is to continue and complement the research. The exercises consist of capturing microclimatic parameters of different environmental scenarios and modifying the temperature of the materials according to the records.

ISSN 2531-2162

The thermal comfort, balance calculated by the application shows if there are significant differences in the environment derived from the colors used in the objects of study.

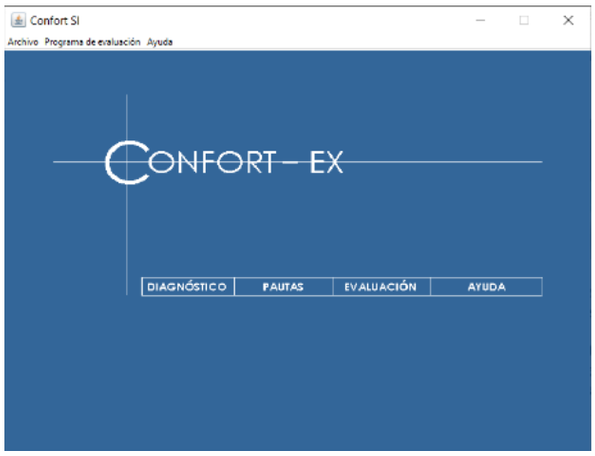


Figure 6 Comfort Ex application
Source: Own Elaboration

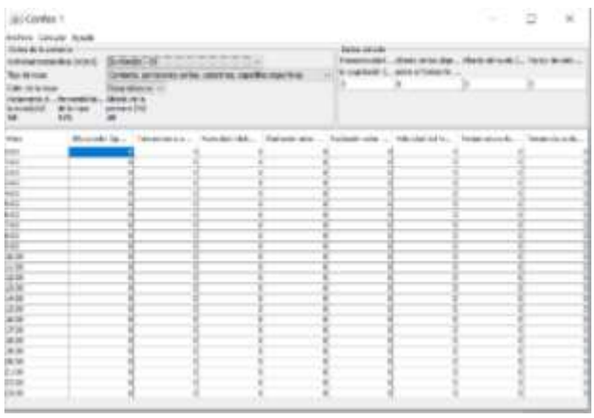
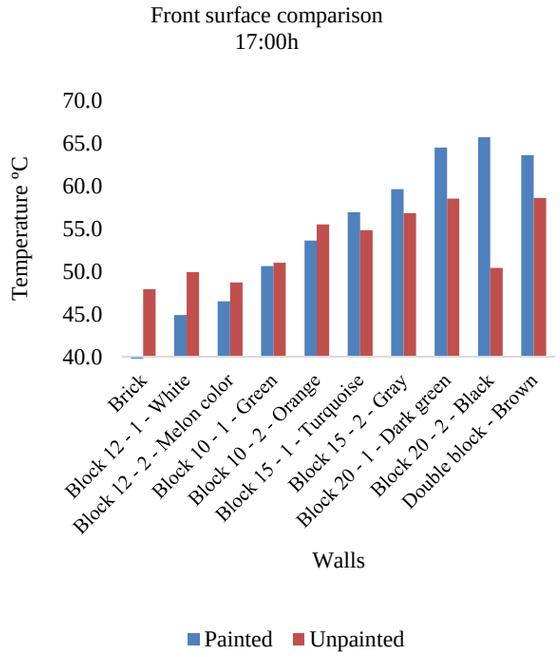


Figure 7 Comfort balance calculation interface
Source: Own Elaboration

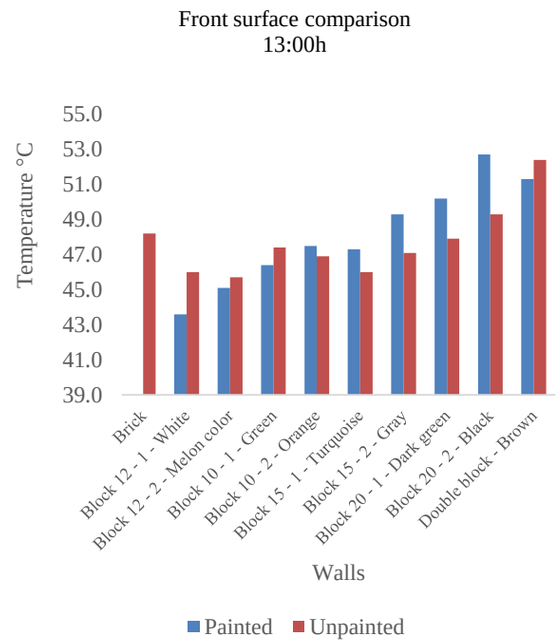
With the above, the first stage of the research is finished and the present document is elaborated.

Results

When comparing the temperatures of the blocks without paint, it can be observed that the maximum difference is 6°C at 13:00 h, which is when the energy accumulates in the material, as shown in graph 1. Once the blocks are painted, it can be observed that the light colors in most of the hours lower the temperature of the walls up to 5°C, while the walls with medium and dark paint increase the temperature of the wall from 7°C to 15°C, as is the case of the black color, as shown in graph 2.



Graph 1 Temperature comparison July 13 17:00 h.
Source: Own Elaboration



Graph 2 Temperature comparison July 21 13:00 h.
Source: Own Elaboration

Regarding the highest temperatures of the walls, they are identified at 17:00 h as shown in graphs 3 and graphs 4, where it is shown that, due to the color, the walls have differences of up to 25ºC. Another thing that is detected is that the thickness of the block does influence the heating of the walls, to the surprise of the research team, the 20 cm block heats up more in the front part than the wall with a thickness of 10 centimeters; and when the temperature of the back part of the walls with similar temperatures is observed.

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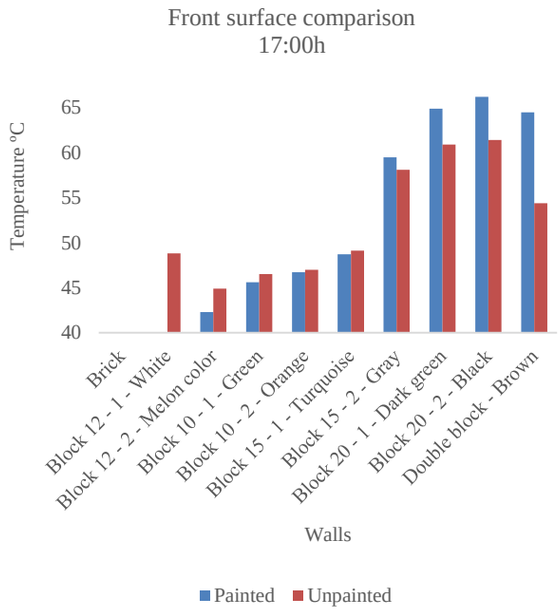
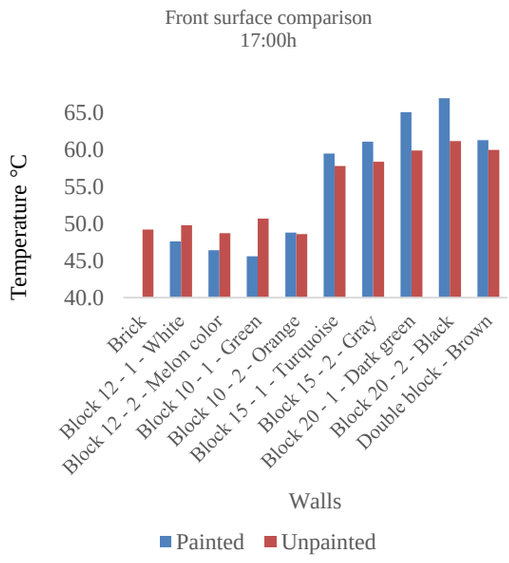
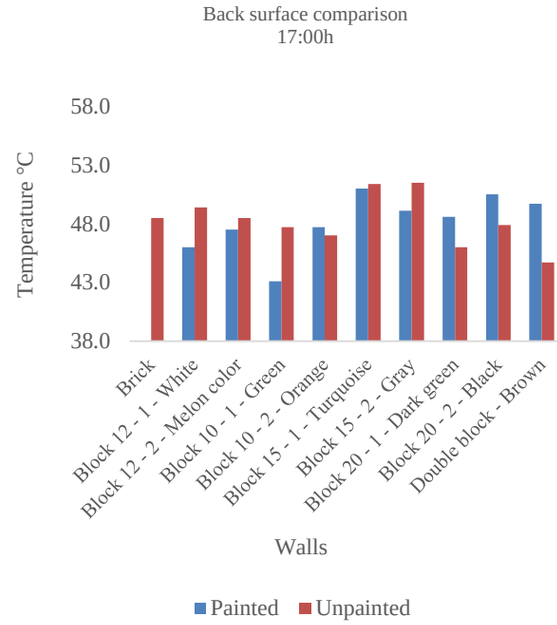
It can be seen that on average, the insulating capacity is better in the 10cm wall and in the 20cm thick wall, as can be compared in graphs 4 vs. graphs 5.



Graph 3 Front temperature comparison 15 July 17:00h
Source: Own Elaboration



Graph 4 Front temperature comparison 21 July 17:00h
Source: Own Elaboration



Graph 5 Back temperature comparison 21 July 17:00h
Source: Own Elaboration

When calculating the thermal comfort balance in the comfort ex application, it is observed that the color does influence the results, but in a relatively small percentage compared to the influence on the temperature of the objects. We speculate that this is since the radiation generated by a block element does not have a significant distance range, so it is inferred that its contribution to the feeling of comfort in the environment is rather long term. This can be verified by approaching the walls to determine the approximate distance at which the sensation of heat is appreciated, which ranges between 30 cm and 40 cm. Therefore, as soon as we move away from the wall, the radiation is no longer felt.

Hours	Absorbed radiation W/m2	Energy balance W/m2
00:00	◦	◦
01:00	◦	◦
02:00	◦	◦
03:00	◦	◦
04:00	◦	◦
05:00	◦	◦
06:00	◦	◦
07:00	◦	◦
08:00	◦	◦
09:00	288.69	-5.42
10:00	◦	◦
11:00	306.77	68.75
12:00	◦	◦
13:00	323.58	182.35
14:00	◦	◦
15:00	381.65	188.46
16:00	◦	◦
17:00	441.02	187.76
18:00	◦	◦

Figure 8 Comfort balance 001, Black color
Source: Own Elaboration

ISSN 2531-2162

Hours	Absorbed radiation	Energy balance W/m2
00:00	º	º
01:00	º	º
02:00	º	º
03:00	º	º
04:00	º	º
05:00	º	º
06:00	º	º
07:00	º	º
08:00	º	º
09:00	291.09	-3.02
10:00	º	º
11:00	308.42	70.41
12:00	º	º
13:00	329.61	187.82
14:00	º	º
15:00	388.61	195.42
16:00	º	º
17:00	421.85	168.6
18:00	º	º

Figure 9 Comfort balance 001, White color
Source: Own Elaboration

Hours	Absorbed radiation W/m2	Energy balance W/m2
00:00	º	º
01:00	º	º
02:00	º	º
03:00	º	º
04:00	º	º
05:00	º	º
06:00	º	º
07:00	º	º
08:00	º	º
09:00	291.09	-3.02
10:00	º	º
11:00	311.83	73.81
12:00	º	º
13:00	331.89	190.67
14:00	º	º
15:00	393.86	200.67
16:00	º	º
17:00	428.29	175.04
18:00	º	º

Figure 10 Comfort balance 001, Gray color
Source: Own Elaboration

Thanks

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Thanks to the architecture research team made up of: Edgar David Contreras Guevara; Julio Cesar Carrillo Briones; Juan Ángel Hernández; Evaristo San Juan Juárez; Luis Felipe Serna.

Conclusions

After the time invested in the bibliographic studies, it can be affirmed that there is no research on the impact of color on the temperature of the walls in the hot subhumid zone, specifically in Ciudad Valles, San Luis Potosi. In the same way, little evidence of research on thermal comfort in interior and exterior spaces in the city is detected when it is considered that it is necessary because the city has an extremely hot climate.

The difference in block thickness does contribute to the time in which the material cools down or heats up; the color difference has more impact on the surface temperature of the material than on the thermal comfort balance of the person, however, it is important to express the assumption that a black urban area can generate a lot of radiant heat that in the end will be transmitted to the air temperature and could generate hot environments for the pedestrian.

It is particularly important to continue this type of research, since they are interesting and with them it is possible to verify and advise home users about the oscillation and maximum differences that the temperature of their walls can present with a specific color, because to date the work team had no exact idea of the differences. It is well known that light colors vs. dark colors are cooler, but it was not known by how many degrees Celsius. The experience, the learning and the results were generated in an objective way, thanks to the application of measuring equipment and the application of calculation software; which was another thing that the team did not know: the fact of creating a link between the measured parameters, in relation to the subjective information about the people to calculate the thermal comfort balance.

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Waterproofing materials used in buildings in the colonial period in Mexico: Case study Huichapan, Hidalgo

Materiales de impermeabilización empleados en edificios en la etapa colonial en México: Caso de Estudio Huichapan, Hidalgo

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Abstract

Mexico, focusing specifically on the case of Huichapan, Hidalgo. The study examines various applied waterproofing techniques, considering factors such as available materials and type of building. The particularities and challenges associated with the implementation of these techniques in a historical context are highlighted, providing valuable actions for the effective conservation of ancient buildings in Mexico. The richness of cultural heritage is emphasized through architectural diversity, highlighting the various types of buildings that stood out during the colonial period in Mexico. This approach not only seeks to document physical characteristics but also to underscore the significant contribution of these buildings to the cultural identity and history of the region.

Conservation, Historical, Contexto

Resumen

El presente documento aborda la temática concerniente a los materiales de impermeabilización que se emplearón en las cubiertas de edificios en la etapa colonial en México, centrándose específicamente en el caso de Huichapan, Hidalgo. El estudio examina diversas técnicas de impermeabilización aplicadas, considerando factores como materiales disponibles y tipo de edificación. Se destacan las particularidades y desafíos asociados con la implementación de estas técnicas en un contexto histórico, proporcionando acciones valiosas para la conservación efectiva de edificios antiguos en México. Se resalta la riqueza de la herencia cultural a través de la diversidad arquitectónica, destacando los diversos tipos de edificaciones que se destacaron durante la época colonial en México. Este enfoque no solo busca documentar las características físicas, sino también resaltar la significativa contribución de estos edificios a la identidad cultural y la historia de la región.

Conservación, Histórico, **Context**

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Introduction

Both current society and our ancestors seek to preserve their heritage, ensuring its longevity, as inheriting a property in which intangible memories and traces of family, community, and societal identity are ingrained is part of the customs in Mexico.

Despite technological advances, there are still areas for improvement in terms of waterproofing, as it is subjected to numerous abiotic and structural factors. It may require a specific formulation for a particular case or a standard that helps regionally identify these heritage sites within a sector with similar characteristics. These issues arise due to the vast complexity of construction systems, with a great mix in historical properties featuring different composite systems or increasing levels of complexity.

Waterproofing can take various forms, ranging from natural to synthetic, all aiming for the common goal of being durable, of high quality, with a good aesthetic finish, and a positive chemical reaction. In the case of historical buildings, it is crucial that the National Institute of Anthropology and History (INAH) is satisfied with the implementation in restoration interventions.

During the colonial era in Mexico, constructions faced specific challenges related to climate, geographical conditions, and available materials. While they did not use modern chemicals like the synthetic waterproofing we know today, colonial-era builders employed local techniques and materials to protect structures against moisture and rainfall.

It is essential to consider that construction techniques and materials used in the colonial era varied by region, local construction traditions, and resource availability. Additionally, colonial constructions often required regular maintenance to preserve their structural integrity and protect them against the elements, including moisture.

Current waterproofing products focus on a generic market without addressing the specific needs of properties with delicate details, such as historical ones.

The INAH is meticulous about restoration procedures, aiming to replicate the original system and materials in interventions. This involves tracing the origins of natural waterproofing throughout Mexico's history, rooted in pre-Hispanic times with lime and vernacular systems, to the present day, where scientific advancements reintroduce the beneficial properties of nopal mucilage. This is implemented not only in historical buildings but also in residential homes due to its affordable cost. The goal is to conserve a long tradition of caring for properties, contributing to a characterization that aids in both cases.

Historical framework

For Castillo M. *et al*. (2004), the roots of Huichapan date back to pre-Hispanic times, showing traces of Teotihuacan, Toltec, Mexica cultures, but above all, the Otomi culture. The name Huichapan, meaning "river of willows," comes from Nahuatl, but the Toltecs named it Hueychapan, meaning "abundance of water."

According to glottochronological studies, this diversification of the name's origin in different cultures is a common characteristic of this area, as it has been inhabited since the Late Preclassic period (600 – 150 B.C.) and belongs to the Bajío of Otopames Mesoamericans and Otomangue origin.

The emergence of the first agricultural remains in Mezquital and Bajío indicates an expansion of sedentary Otopames from the valleys of Mexico and Toluca towards the north, with a possibility of having joined or displaced the Pames. Wright D. C. (2005).

During the Protoclassic period in the Mezquital Valley, the absence of pottery is observed, suggesting the depopulation of a large area of this region. This is argued by the dispersed population concentration related to Teotihuacan in the southern part of the valley. Noteworthy architectural features include bases with slope and board, buttresses on the sides of staircases, lime-based coatings, and braziers. Brambila R. *et al*. (2013).

For the Classic period (200-600 A.D.), they were re-colonized by Teotihuacan rulers, living in multifamily residential complexes.

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Teotihuacan sites in Mezquital show strong similarities to the metropolis in their architecture. Residential complexes were made of stone, lime, and wood, and it is very likely that Teotihuacan colonies in Mezquital produced lime for the metropolis, with wood probably extracted from the forested areas of the region. However, this architectural-commercial harmony declined by the 5th century.

During this new period, the "culture of the tables" or "Xajay culture" emerged. Together with Bajío, they used the "closed courtyard," with a rectangular perimeter platform, usually with a base on one of its sides. Wright D. C. (2005).

During this time, evidence of the use of lime within buildings as a coating and protection material was found. This was not only by the Teotihuacans in their city, but also the Mezquital area, responsible for providing tribute in this material. This provided knowledge in this area for its own use, although it was not intensive due to sending a fixed tribute, it was crucial to analyze how it behaved with the specific climate and vernacular systems of the region.

With the dissolution of Teotihuacan, lime was only used in the Mezquital Valley. Although the veins had been exploited and were no longer sought after, those that remained continued to be used until the resource was exhausted. In constructions, its implementation is noted in a measured manner without excess, reflecting the care they had with this raw material.

During the 16th century, there was a process in which the Otomis of Mezquital expanded into Pame territory in the Eastern Bajío, but never in a procession-like manner.

With the arrival of the Spaniards on the Mexican coasts in 1519, a period of conquest and evangelization began, creating a large network of processions and missions of different religious orders alongside military campaigns and settlements. The Franciscans prevailed during this time.

In 1531, Huichapan was subdued by the chief of Jilotepec, Don Nicolas Montaña, originally from Tula and a relative of Moctezuma II. Montaño was appointed Captain General of the places near Querétaro, a designation he received from Viceroy Velasco on behalf of Carlos V. With this, he managed to have contact with Fernando de Tapia (Conín), who had been present in Huichapan before the conquest as a merchant (being originally from Nopala, forming his family in the current capital of Queretaro in the Cañada area. Engaging in trade with the Mezquital - Kingdom of Jilotepec area, managing links and contacts between different ethnic groups), passing his title on to his son Diego de Tapia, who was also present in Huichapan, but now for the designation of encomiendas, having knowledge of routes and settlers from his father. Brambila R. *et al*. (2013).

Thus, in 1532, the Valley of San Mateo Huichapan was founded. Francisco de Alejos led the main family that settled the town. None of those who accompanied Montaño in his campaign stayed to populate Huichapan, so the "Alejos" arrived later with "Alejos de la Bárcena" to settle the place, requesting permission to found the town along with other families, including that of Don Diego de Tapia. In January 1557, the founding of "Valle de San Mateo Gúeychiapan" was officiated in Jilotepec. Castillo M. *et al.* (2004).

In the 17th century, Friar Felipe de Santiago contributed to the writing of the "Huichapan Codex," a document that narrates part of indigenous history and the colonial designation that would be known as the entire regional history. Santiago F. *et al*. (1632).

In present-day Huichapan, it is common to find constructions from the 16th to the 20th century where the roofs show significant wear or even total collapse and loss of slab. It is worth noting that there is a category of Religious Architecture, where buildings belong due to their massive and monumental character. Figures 1 and 2 show, through artistic representation, the main facade and architectural plans of a chapel as a representation of religious architecture.

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Figure 1 Composition of the main facade of a chapel as a representation of religious architecture in Huichapan, Hidalgo
Source: Own Authorship

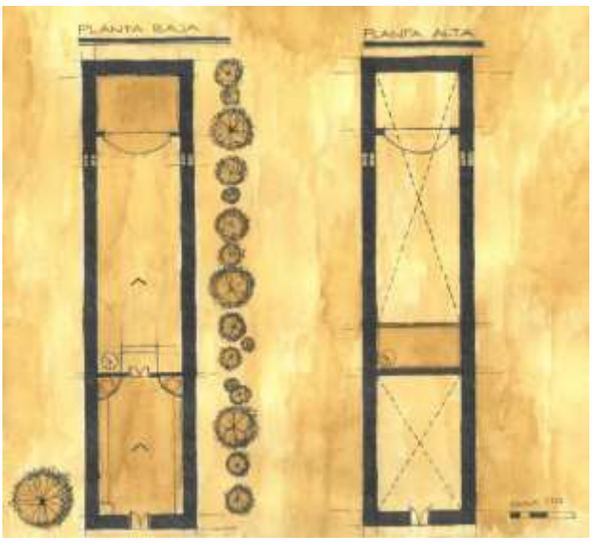

Figure 2 Architectural floor plans of a chapel as a representation of religious architecture in Huichapan, Hidalgo
Source: Own Authorship

Civil Architecture

There are two types; the first consists of constructions with architectural elements and religious precedents that play a significant role together. The second is on a smaller scale, involving residences that define and complement the urban landscape. As examples, in Figure 3, we identify a graphic model of an arcade-type building as a representation of civil architecture in Huichapan. Meanwhile, in Figure 4, we observe the architectural typology of a residence.

Figure 3 Graphic model of an arcade-type building as a representation of civil architecture in Huichapan, Hidalgo
Source: Own Authorship

Figure 4 Graphic model of an arcade-type building as a representation of civil architecture in Huichapan, Hidalgo
Source: Own Authorship

Materials

As mentioned by Cedeño (2019), the term "humidity" refers to the water that permeates a body. This moisture can come from the subsoil, the air, or the effects of rain. In the field of construction, water will always be the number one enemy of building materials. Therefore, to prevent water from impregnating these materials, it is necessary to consider waterproofing methods.

Thus, preventing water from passing through a porous body is called impermeability, and the material that performs this function is known as a waterproofing agent. In ancient times, materials such as straw, leaves, branches, and slate slabs were used. In Mexico, waterproofing with alum, soap, prickly pear cactus, and aguacal was widely employed.

Some of the methods and materials used to waterproof buildings in the colonial period in Mexico included:

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Lime and plaster: Lime and plaster were common materials used in colonial construction. These materials had properties that helped repel water and prevent leaks in the walls. Lime was also used to create stuccos that could serve as waterproof coatings.

Clays and adobe: Local clays and sun-dried adobe bricks were basic components of many colonial constructions. These materials could be treated and mixed in a way that helped resist water penetration.

Clay tiles: Fired clay tiles were common on the roofs of colonial constructions. Properly arranged, these tiles formed an effective barrier against rain and provided a drainage system to prevent leaks.

Stone: In some constructions, especially those of historical significance, stone was used as a building material. Careful arrangement of stones and the use of mortars could help minimize water entry.

When analyzing the historical context of Huichapan, it is noted that they implemented a carpentry and cabinetmaking system widely used by Adalberto Jiménez, a local resident considered a great master craftsman who passed away in the seventies. He inherited the method of making "glue" (glue made from gelatinous parts of animals), which was sold in plates or pieces. These had to be soaked and then subjected to a "double boiler" for gradual dissolution since direct heat would burn it (Sánchez F., 2015).

By combining these facts and the composition of the "glue," it could be inferred that it is a triggering factor within colonial architecture in this municipality, as it was applied as a sealer and for curing wood. Specifically, it was the wooden beams that collapsed first, compromising the entire slab system. The wall system did not show the same exhaustion, standing without fractures, only exhibiting some gradual or significant dampness due to the failure of the main roof.

In Figures 5 and 6, we identify the wooden beams and their importance within the slab system, as well as their behavior in conjunction with the building as part of the construction and structural system.

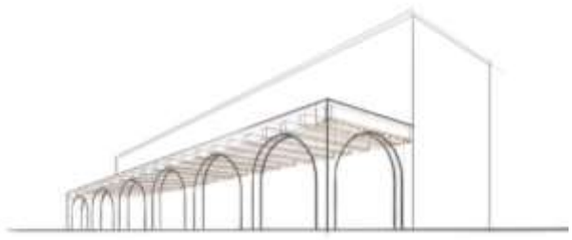

Figure 5 Composition of wooden beams in the archetypal arcade, represented in a two-point perspective on the section of wooden beams in colonial arcade porches, very common in New Spanish architecture
Source: Own Authorship

Figure 6 Composition of wooden beams in the archetypal colonnade, represented in a two-point perspective on the section of wooden beams in unadorned colonnade porches
Source: Own Authorship

Typology

The facades are characterized by a tendency towards horizontality with smooth alignments, simple parapets, and varying ornamentation, either with molding stripes or carvings that serve to protect against splashes and direct rain, especially in the corners where construction tends to be more critical, including openings.

The construction system presented in Huichapan ranges from a degree of simplicity to a certain degree of opulence, featuring materials such as stone, composite walls, wood, and an abundance of quarry.

As observed in Figure 7, when broken down, the structural relevance of a single clear span of the slab becomes apparent. It tends to be vulnerable to moisture from rain, exhibiting a tendency to flex in the slab and consequently sagging in the middle where the critical point is located.

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Figure 7 Composition of wooden beams in the archetypal colonnade. Two-point perspective representation on the section of wooden beams in colonnade porches, where the structure is marked up to the midpoint of the entire porch section, highlighting the critical point
Source: Own Authorship

It is important to analyze these diagrams to diagnose how materials behave, where there is a tendency to flex in the slab and consequently sag in the middle where the critical point is located.

Considering the above, we can understand why there are so many failures in slabs of this type in the Huichapan region. The practice of "waterproofing" is seen as a construction method by covering the beams with traditional cabinetmaker's glue, neglecting the external waterproofing of the structure as a final finish and protective coating. This method becomes outdated due to its natural composition and lack of internal-external complementation.

Results

Architectural and material surveys were conducted on various buildings from the colonial period in Huichapan, encompassing structures of both religious and civil nature (residences). This allowed us to identify the different nature of materials used in construction, as well as the waterproofing agents incorporated into the buildings. Through this process, sketches of architectural representation (prototypes) were developed with the aim of assessing the current state of the work concerning its performance regarding the employed waterproofing.

In Figures 8 and 9, we observe the architectural and tectonic plans, as well as a schematic section of a religious building, respectively, as part of the comprehensive technical data sheet for construction systems and materials incorporated into religious buildings.

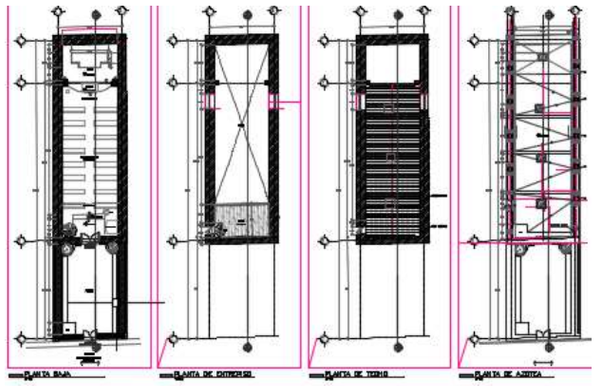

Figure 8 Architectural and typological plan of a religious building as part of the technical data sheet concentrating on construction systems and materials used in religious buildings
Source: Own Authorship

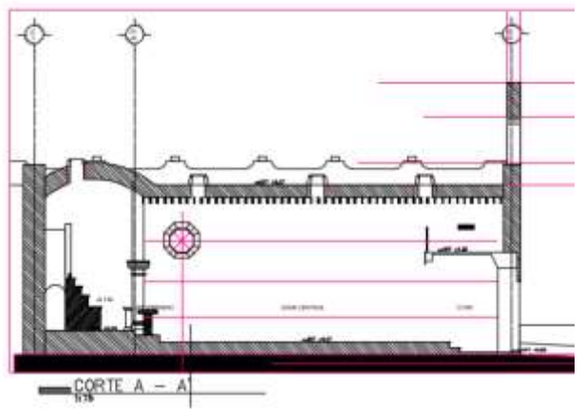

Figure 9 Typical schematic section of a religious building as part of the technical data sheet focusing on construction systems and materials used in religious buildings
Source: Own Authorship

In Figure 10, we observe respectively the typical architectural facade of a civil building as part of the technical data sheet focusing on construction systems and materials used in religious buildings.

Figure 10 Schematic facade of a civil building as part of the technical data sheet concentrating on construction systems and materials used in religious buildings
Source: Own Authorship

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Gratitudes

The publication of this article would not have been possible without the interest and commitment of a group of colleagues and researchers who undertook the task of supporting the development of the case study presented through a practical methodology to solve problems related to the conservation of architectural heritage. I appreciate the collaboration of researchers: TREJO-TORRES, Zaira Betzabeth, MSc. BENÍTEZ-ALONSO, Margarita, BSc. for the development of this article. I appreciate the comments of RUFINO – MENDOZA, Mauricio Abraham, BSc. regarding the theme of architectural elements and components.

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Conclusions

As we managed to synthesize the wear factors and agents that cause deterioration in roofs of historical-colonial buildings, we could observe that the relationship between construction methods influences significantly, not just the abiotic factors alone over time. This implies that a harmony must be achieved between waterproofing and coating both internally and externally to balance the wear and failure of the structural system. In this case, noticing the presence of wooden framework, one might suggest replacing it with a more modern and less perishable material.

However, in compliance with INAH regulations to preserve the identity and maintenance of these buildings, the materials and execution methods must be respected for any intervention. Hence, the relevance of seeking a solution where the formulation of the waterproofing is composed of ingredients that have shown favorable precedents in their behavior over time in preserving these properties.

An example is the use of lime, which dates back to pre-Hispanic times. It behaves differently depending on the vein from which it is extracted, the method of exploitation, as well as the customs and uses for its application, the region's temperature, and the proportions. For instance, in the constructions of the Mezquital Valley during Teotihuacan's dominance, lime was used sparingly, in almost light layers, leaving traces. However, after the fall of Teotihuacan, its use increased, and thicker layers were applied. Similarly, the abundance of prickly pear cactus, with multiple variants, each with distinctive characteristics, went relatively unexplored or endemic.

This was not mere chance because while in the southern region of the country the Mayans also implemented lime-based waterproofing or sprayed seashells, a political-commercial relationship can be observed between Diego de Tapia and the active area from La Cañada to Jilotepec, a product of his father's contacts and even a factor in founding Huichapan itself. Although it is no longer a splendid reign or under the commercial yoke of a stronger civilization, mestizaje allowed these knowledge integrations and the creation of new, somewhat experimental, somewhat secure systems, leaving us a legacy where we can improve to preserve our identity and deconstruct ourselves for the benefit of modern society.

It was gratifying to see that the "glue" is considered good for carpentry and applied to architecture, making its presence a demonstration of the local identity. Hence, the importance of observing not only the current environment but also what causes it and since when. For example, vernacular architecture indicates the use of simpler, almost curved-linear joints, while the colonial era explores mixed systems with more marked archetypes.

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However, one is not necessarily better than the other, and the best aspects of both should be preserved. In the case of the waterproofing based on the present research, the goal is to create a friendly, durable formula that the current population can apply to continuously contribute to the care not only of historical heritage but also of their own current heritage that they will pass on to their children.

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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

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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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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.

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This documentation will allow a more precise analysis of the conditions of the object to be intervened 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.

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- 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-católica/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.

ISSN 2531-2162

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 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.

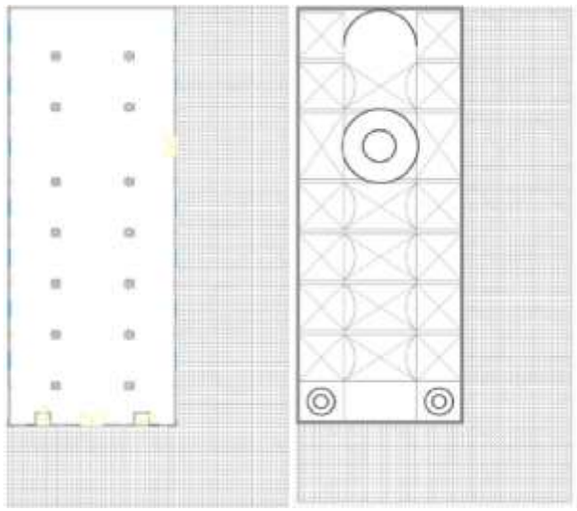
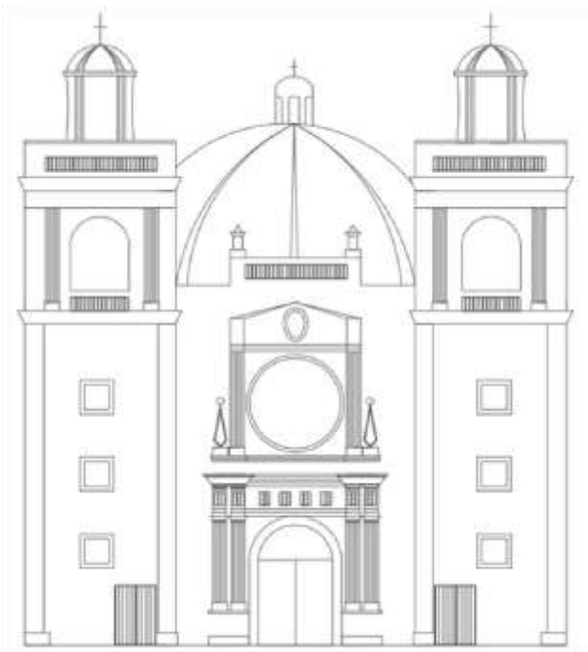


Figure 4, 5 Architectural plan and overall plan of the nave of the Basilica
Source: Own Elaboration



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

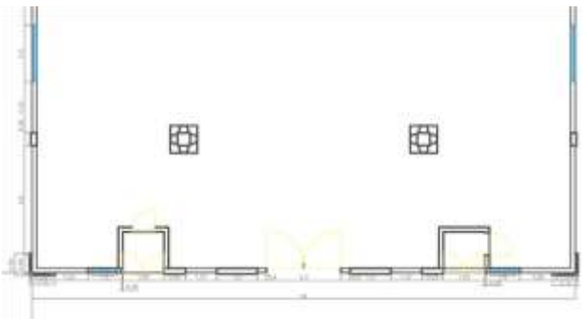


Figure 7 Measurements of the main façade of the Basilica of Our Lady of Guadalupe
Source: Own Elaboration

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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.

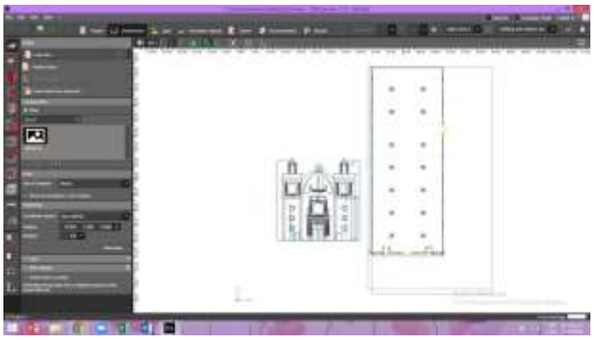

Figure 8 DWG file imported to the DIALux program of the ground plan and the main façade of the Basilica
Source: Own Elaboration

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

ISSN 2531-2162

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

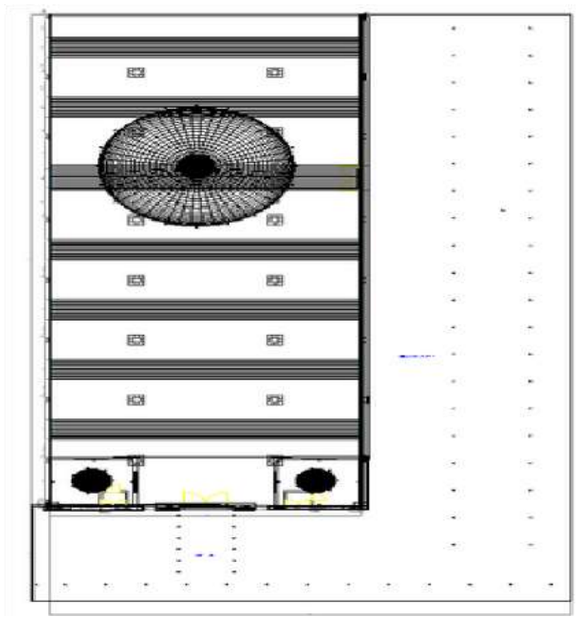

Figure 12 Architectural plan of the proposed luminaire of the Basílica menor de nuestra señora de Guadalupe, "La Villita", elaborated with the DIALux program
Source: Own Elaboration

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.

Table 2 Images with description of the luminaire to be used in the project. Prepared with the DIALux program
Source: Own Elaboration

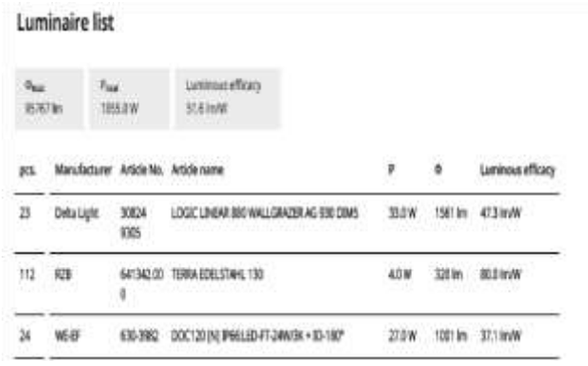

Table 3 Description of the luminaires to be used in the project. Prepared with the DIALux program.
Source: Own Elaboration

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

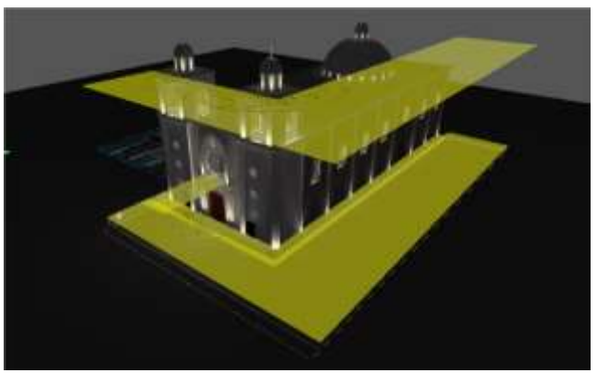

Figure 12 3D model of the minor Basilica of Our Lady of Guadalupe, "La Villita", showing the useful plan, elaborated with the program DIALux
Source: Own Elaboration

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.

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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.

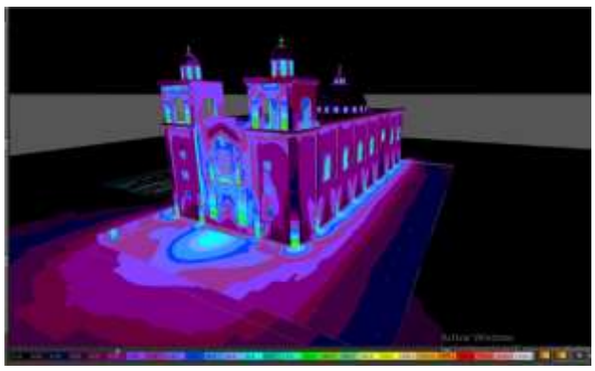

Figure 13 3D modeling of the minor Basilica of Our Lady of Guadalupe, "La Villita", where the false colors are shown, elaborated with the DIALux program
Source: Own Elaboration

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.

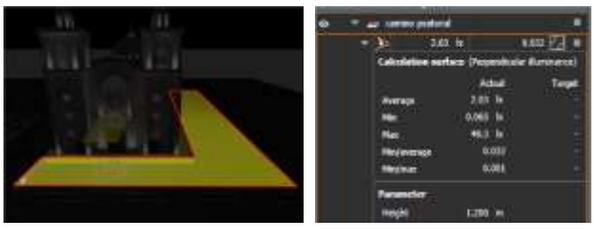

Figure 14 3D modeling of the Basilica Menor de Nuestra Señora de Guadalupe, "La Villita" with the amount of lux used in the area outlined in red
Source: Own Elaboration

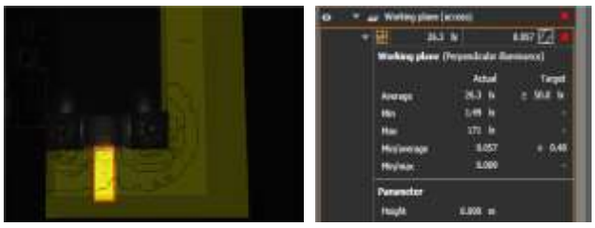

Figure 15 3D modeling of the Basílica Menor de Nuestra Señora de Guadalupe, "La Villita" and amount of luxes used in the area outlined in red, Elaborated with the DIALux program
Source: Own Elaboration

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.

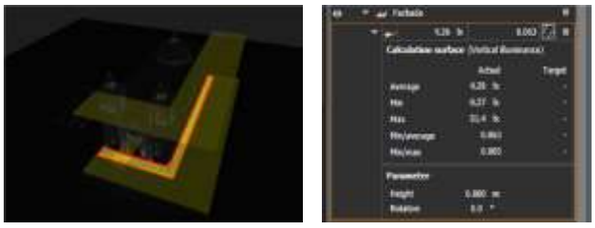

Figure 16 3D modeling of the Basilica Menor de Nuestra Señora de Guadalupe, "La Villita" and amount of lux used in the area outlined in red
Source: Own Elaboration

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.

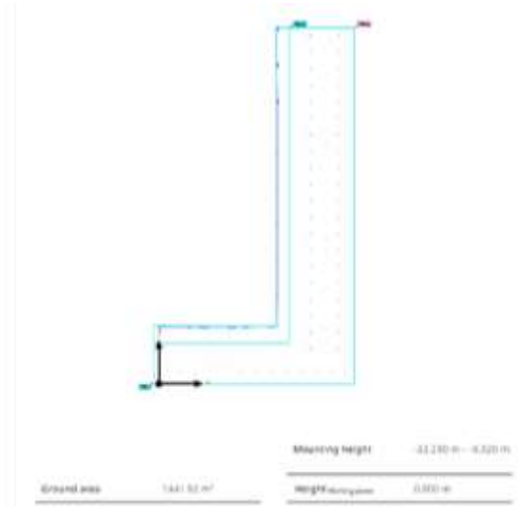

Figure 17 Plan of luminaries of the Basílica Menor de Nuestra Señora de Guadalupe, "La Villita"
Source: Own Elaboration

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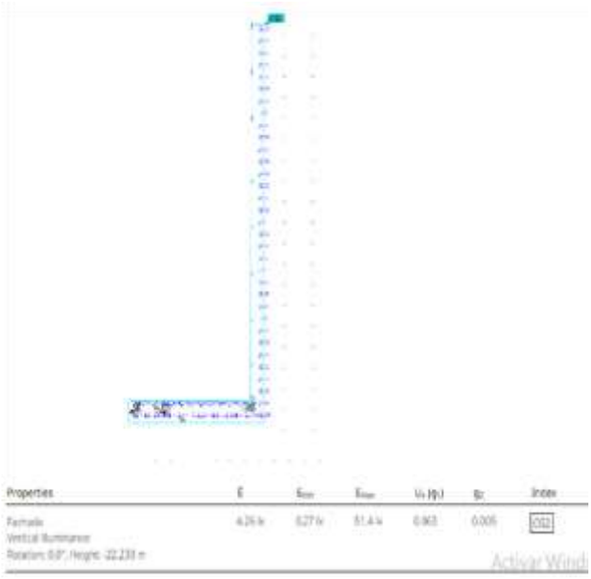

Figure 18 Plan of luminaries of the Basílica Menor de Nuestra Señora de Guadalupe, "La Villita"
Source: Own Elaboration

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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Redesign of Roads for the optimization of Urban Space, integrating a Sustainable Mobility

Rediseño de Vialidad para la optimización del Espacio Urbano, integrando una Movilidad Sostenible

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Abstract

This paper addresses "Redesign of the rural roads of the municipal capital of Huichapan, Hidalgo", in order to generate the optimization of the Urban Space and integrate a Sustainable Mobility, through the analysis of the case study of Huichapan, Hidalgo, Mexico, which is a rural municipality, is characterized by being dispersed, faces specific mobility challenges such as coverage and availability. Together with its structure of narrow, winding streets that sometimes lead to dead ends. This paper addresses the implementation of a cycle path as an integral solution that benefits mobility, health and local economy, as a reference for the restructuring of dispersed urban-rural settlements. The initiative seeks to adhere to the national goals of sustainable urban development, considering the image of a magical town and the rich history of Huichapan, as an initiative that adapts to the context and exalts its qualities.

Municipal, Rural, Sustainable

Resumen

En el presente artículo se aborda el rediseño de la vialidad rural de la cabecera municipal de Huichapan, Hidalgo, a fin de generar la optimización del Espacio Urbano e integrar una Movilidad Sostenible, mediante el análisis del caso de estudio de Huichapan, Hidalgo, México, el cual es un municipio rural, se caracteriza por ser disperso, enfrenta retos de movilidad específicos como es la cobertura y disponibilidad. Aunado a su estructura de calles estrechas, sinuosas que en ocasiones conducen a callejones sin salida. En el presente trabajo se aborda la implementación de una ciclovía como una solución integral que beneficia la movilidad, salud y economía local, como un referente para la reestructuración de los asentamientos urbanos-rurales dispersos. La iniciativa busca apegarse a los objetivos nacionales de desarrollo urbano sostenible, considerando la imagen de pueblo mágico y la rica historia de Huichapan, como iniciativa que se adapta al contexto y exalta sus cualidades.

Municipal, Rural, Sostenible

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† Researcher contributing as first author.

Introduction

Huichapan is a rural municipality located in the state of Hidalgo. Its urban structure is dispersed and monofunctional, featuring a mixed type of layout with a reticular typology in the center and broken plate typology in the peripheries. It has a territorial extension of 660 km2. According to data from INEGI (2020, cited in the Huichapan Municipal Development Plan 2020-2024), "Huichapan has a total population of 47,425 inhabitants, of which 7.3% of the population have some form of disability, such as motor, visual, auditory, speech, and/or mental limitations."

A relevant fact to mention is that the municipal seat was classified as a Pueblo Mágico (Magic Town) in 2012 and recently as Zona de Monumentos Históricos (Zone of Historical Monuments). These two events can significantly enhance tourist influx to the municipality, making it necessary to redesign the current mobility, which is still dependent on cars and public transportation to visit surrounding communities.

As a rural area, public transportation is the primary means of transport, used by 78% of the resident population, followed by cars at 14%, and bicycles at 6.07%, as shown in Figure 1. It is important to note that, being a rural municipality, the bicycle is one of the main means of transportation within communities, which tend to be connected by dirt roads.

Figure 1 Huichapan's Movility
Authorship: Own, based on INEGI data, 2020

Theoretical Framework

An urban design that prioritizes the use of non-motorized transportation is essential for the transformation of population centers towards a resilient design.

This approach aims to encourage the use of mobility alternatives that help reduce greenhouse gas emissions and improve air quality, promoting a more sustainable urban environment. "The concept of resilient cities constitutes an emerging metaphor to describe and interpret the capacity shown by some to face adversities, the origin of serious impacts that questioned their future, managing to recover and continue their development process." Méndez, R. (2012).

The proposed resilient design is based on the premise of prioritizing the use of non-motorized transportation and is linked to a healthy lifestyle that promotes walking and cycling as forms of transportation. This approach helps combat sedentary behavior, reduce lifestyle-related diseases, and improve the overall health of the population. "The built environment, the existing mobility system, and the perception of its inhabitants have now been proven to influence the choice of the mode of movement (means, routes)." Spadaro I., Rotelli C., & Adinolfi P. (2023).

The primary goal of the project is to drive urban improvement towards a resilient city with competitive mobility that also promotes physical activity and prioritizes the reduction in hydrocarbon usage. According to Camagni *et al.*'s argument (2002, cited in Yucesan *et al*. 2024), "urban mobility is currently a crucial component in the debate on sustainable urban development, given the economic, social, and environmental impact for which it is responsible".

On the other hand, the primary theoretical contribution lies in the restructuring of urban and rural mobility patterns in diffuse traces. This includes the proposed territorial planning and urban development in the study area to contribute to the National Program for Territorial Planning and Urban Development (PNOTDU) 2021-2024, specifically targeting Objective 3: "Transition to a model of urban development oriented towards sustainable, orderly, equitable, fair, and economically viable cities, reducing socio-spatial inequalities in human settlements" (Government of Mexico, Territorial Development, 2021). This objective is accompanied by specific strategies and actions, such as:

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Priority Strategy 3.1: Strengthening the Normative Framework for Urban Development Towards Well-being with Emphasis on Social Participation and Reduction of Inequality.

3.1.4: Promote the design and implementation of norms and programs for environmental promotion and sustainable development with the participation of those responsible for urban infrastructure, equipment, services, transportation, and other aspects related to urban development.

Priority Strategy 3.5: Develop and Implement Programs and Projects that Address Urban and Environmental Issues comprehensively in terms of public space, equipment, and mobility.

3.5.1: Promote the normative framework that drives mobility policies and Design-Oriented Transportation (DOT), with criteria for universal accessibility and considering citizen participation.

Contextual Framework

As mentioned, the study area is the municipal seat of Huichapan and the surrounding communities. It is relevant to clarify some important historical data regarding the historical influence of this location.

According to information from the INAH Mediateca, "The city of Huichapan was founded in the 16th century on an ancient Otomi pre-Hispanic settlement." (2004) Huichapan is one of the richest municipalities in Hidalgo in terms of history and culture. It was designated as Pueblo Mágico in 2012, being the site where the first commemoration of Grito de Independencia (Cry of Independence) took place on September 16, 1812.

Similarly, in the Official Gazette of the Federation published on June 30, 2023, the Presidency of the United Mexican States issues the "DECREE declaring the area of 66-67-30.6 hectares in the locality of Huichapan, municipality of Huichapan, state of Hidalgo, as a Zone of Historical Monuments" for the benefit of the conservation and safeguarding of buildings constructed during the 16th to 19th centuries. This area is located at coordinates E 432193.26 and N 2253149.15, corresponding to UTM Zone 14 North, as shown in Figure 2.

Figure 2 Plan of the Historical Monuments Area in Huichapan, INAH 2023

In addition, it is important to mention that the street typology of Huichapan consists of narrow, cobblestone streets, ranging from 6 to 8 meters in width, accommodating two-way traffic, with sidewalks less than 1 meter wide. This necessitates the redesign of vehicular routes and sufficiently wide sidewalks to ensure wheelchair accessibility and universal access in general. Furthermore, it is essential to adhere to the urban image outlined in the Urban Image Regulation for the Municipality of Huichapan, Hidalgo.

Within this regulation, there is a stipulation regarding the need for all elements such as signage and lighting to maintain a design, proportion, and color congruent with the environment, physiognomy, and image of the area in which they are located. The use of materials and plants from the region is encouraged, considering that Huichapan is an area with a mining industry for construction raw materials. These materials are exported to other states and countries, The Huichapan Municipal Government (2020) summarizes that "The main international sales in 2020 were Cubes, Dice, and Similar Articles for Mosaics, of Natural Stone (US$5.67M)." Consequently, the abundance of this material allows houses, government buildings, and places of worship to feature structures and facades made of natural stone, with quarry stone being the predominant material, characteristic of its urban image.

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Hypothesis

In this scenario, it is proposed that the implementation of an urban design with non-motorized ecological transportation in the municipality of Huichapan, specifically in the communities of Huichapan, El Cajón, Pedregoso, La Sabinita, Sabina Grande, San José Atlán, El Saucillo, Vitejhé, Estación Huichapan, Santa Bárbara, Ejido de Huichapan, and San Mateo. Among these communities, Huichapan, La Sabinita, San José Atlán, and Estación Huichapan, will improve mobility, encourage bicycle usage, and promote a healthy lifestyle. The proposal for the creation of alternative routes will benefit traffic circulation, while a bike lane will boost the local economy by increasing safe road access and interconnection between communities.

Justification

A bike lane is a road element that reduces the use of motorized vehicles and allows users mobility independence, promoting physical activity. The added value in rural road design for dispersed areas involves going beyond mere functionality, incorporating aspects that can improve the lives of residents in communities. This includes inclusive design to ensure coverage of the needs of all inhabitants, including infants, adults, seniors, individuals with disabilities, cyclists, motorists, and transporters. Ensuring equitable mobility requires engaging communities in the design process to better understand their needs and ensure that the project benefits the local population, as asserted by Spadaro I., Rotelli C., & Adinolfi P. (2023). The configuration of the built environment, the existing mobility system, and the perception of its inhabitants are factors that influence the choice of mode of transportation, whether in terms of means used or routes selected.

Description of the Method

The following are the steps followed in the research:

1. Problem Identification:

The project is currently located in the state of Hidalgo, specifically in the municipality of Huichapan, as shown in Figure 3.

Figure 3 Location of the Municipality of Huichapan, Hgo. INEGI, 2021

The study area is limited to the municipal seat of Huichapan, focusing on three points or nodes with the highest population concentration: Huichapan, San José Atlán, and El Saucillo, as well as the surrounding communities mentioned earlier. This area has a population of 9,853 inhabitants and stands out as the zone with the highest volume of vehicular traffic. On the other hand, the settlement of San José Atlán is home to 3,546 inhabitants, as shown in Figure 4. El Saucillo is also considered due to its population of 625 inhabitants and a student population of 2,643. This is because it is the location of the region's public university, the Instituto Tecnológico Superior de Huichapan (ITESHU). Consequently, public transportation routes follow a fixed path from Huichapan to San José and El Saucillo due to high demand. This situation provides an opportunity to drive improvements along this route with the goal of transforming mobility in the region.

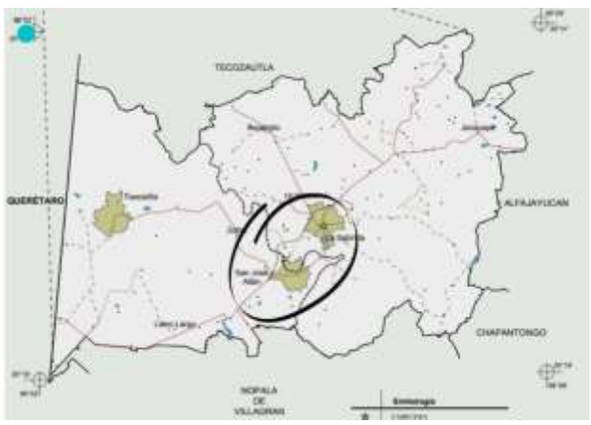

Figure 4 Main Study and Intervention Areas. Author's own work, based on INEGI map, 2010.

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2. Research and Analysis

Urban Structure of Huichapan

The municipal seat of Huichapan currently has a reticular urban structure organized with two main roadways running North-South and East-West, as observed in Figure 5. However, on the outskirts, there is a noticeable distortion of this layout, leading to an irregular typology, indicating that the population has grown in a disorderly manner.

Figure 5 Figure-Ground of the Urban Layout of the Municipal Seat of Huichapan
Source: Project archive, 2023

Urban Structure of San José Atlán

Moreover, the community of San Jose Atlán exhibits a linear and irregular urban structure, as seen in Figure 6. It is characterized by dispersed growth without a planning scheme regulating the population expansion experienced in the last 12 years. In this context, the absence of systematic planning is evident, leading to a fragmented urban configuration without clear organization.

Figure 6 Figure-Ground of the Urban Layout of San José Atlán
Source: Project archive, 2023

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Urban Image of Huichapan

Quarry plays a fundamental role in Huichapan as a key raw material in construction. Its presence is evident in the streets, where it stands out as a predominant element used in the construction of church facades, houses, cobblestones, moldings, sidewalks, columns, foundations, walls, among others, as shown in Figures 7-8. Thanks to its abundance, quarry has become a crucial resource in the construction industry in the region, contributing significantly to its development.

Figure 7 Facades of Huichapan
Source: Project archive, 2023

Figure 8 Photograph of the Streets of Huichapan
Source: Project archive, 2023

Nowadays, the architecture of the region stands out for its distinctive style, employing the construction system of adobe and stone walls, along with flat roofs supported by wooden beams, planks, and bricks. On the exteriors of the buildings, smooth finishes are noticeable, with openings framed in quarry and window protection using ironwork. This design contributes to the distinctive aesthetics of local architecture, merging functionality with decorative elements.

Regarding interior design, the presence of a central or side courtyard prevails in most constructions, accompanied by porticoed corridors, as seen in Figure 9. Additionally, it is common to find orchards in the rear, adding a green and natural component to the architectural environment. This focus on internal layout reflects the historical and cultural significance of outdoor living in the region.

Figure 9 Photograph of the Interior Garden of the Casa de la Cultura, Huichapan
Source: Project archive, 2023

Urban Image of San José Atlán

San Jose Atlán showcases civil architecture characterized by the use of brick and block in confined masonry walls as the main construction element. Architectural finishes tend to be rustic in style, with the presence of unfinished construction (obra gris) prominent in many buildings, as seen in Figures 10-11.

The use of brick and block, as predominant construction materials, imparts a solid and durable appearance to the structures. The preference for these materials may stem from their local availability, affordable cost, and versatility in construction.

Figure 10 Photograph of the Main Road in San José Atlán
Source: Project archive, 2023

Figure 11 Photograph of the Main Road in San José Atlán
Source: Project archive, 2023

3. Definition of Objectives and Design Criteria

The design aligns with the specific characteristics of the study area, where population density is low, at just 71.8 inhabitants per square kilometer. Consequently, mobility needs may differ from those in dense urban settlements. The primary goal is to ensure accessibility, connecting communities and facilitating smooth journeys, whether in motorized or non-motorized vehicles, without compromising the urban image. The use of predominant regional materials aims to minimize environmental impact while highlighting the beauty of rural areas.

4. Urban Model to Apply

The bike lane overlays the main road that directly connects the three main population centers, branching off to cultural and historically significant sites. Considering the street typology in some areas, an alternative route is chosen along the immediately parallel street to avoid vehicular obstructions.

5. Generation of Design Options

Intervention Route:

The central proposal for the intervention route focuses on the San José Atlán-Las Rosas road, connecting the localities of Huichapan, San José Atlán, and El Saucillo. This road, with a total length of 9.4 km, plays a crucial role as the main transportation route for residents and students traveling from the municipal seat to ITESHU. See Figure 12.

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Figure 12 Route connecting San José Atlán with Huichapan Hgo.
Source: Project archive, 2023

In the stretch from San José Atlán to Huichapan, the road has an average width of 14.62m. This dimension provides an opportune space for implementing a bike lane, aimed at promoting the use of bicycles as a means of transportation, along with the creation of two dedicated sidewalk spaces. The inclusion of these elements will significantly contribute to improving the safety and comfort of pedestrians and cyclists using this route, fostering a more friendly and accessible environment.

The second intervention stretch covers the distance between the El Saucillo-San José Atlán communities, with a total of 5 km to be addressed. This stretch is considered crucial in the intervention plan as it connects two significant localities and contributes significantly to regional connectivity. In Figure 13, we can observe the current state of the road that is planned for redesign.

Figure 13 Current road condition from San José Atlán to the expansion section to 4 lanes
Source: Project archive, 2023

Results

A route for the implementation of the bike lane was generated, considering the inclusion of nodes as rest and community meeting points. This strategy aims to use existing centers to encourage participation in new leisure activities, optimizing the use of public spaces for various activities, as seen in Figure 14.

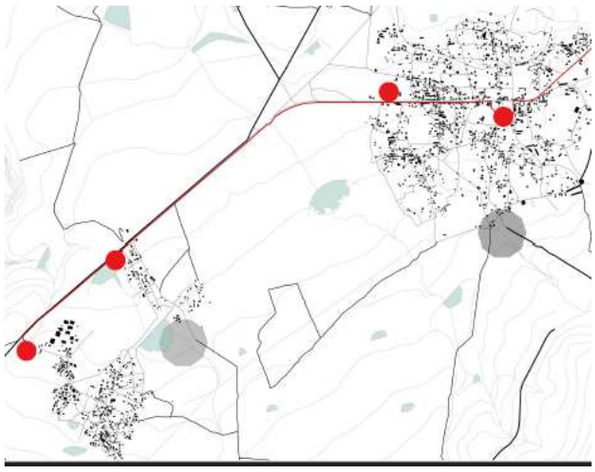

Figure 14 Location of the design proposal and nodes to design and redesign
Source: Project archive, 2023

The bike lane in the San José Atlán - Huichapan stretch aims to preserve the two existing vehicular lanes while incorporating a bike lane and two sidewalks for pedestrian use, as shown in Figure 15. This proposal seeks to provide a comprehensive solution that promotes sustainable and safe mobility for the local population.

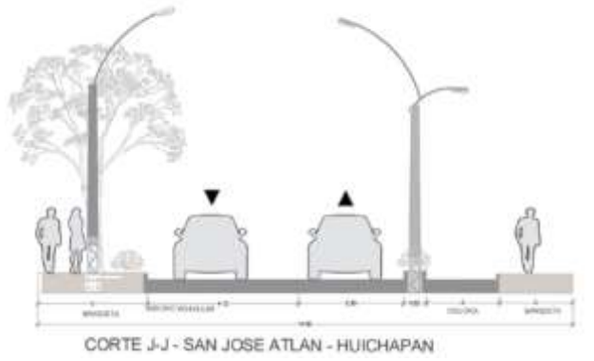

Figure 15 Road design proposal for the San Jose Atlán - Huichapan stretch
Source: Project archive, 2023

As part of the intervention plan in downtown Huichapan, the reconfiguration of J.M. Pedraza Street and Patoni Street is considered. The main purpose is to optimize traffic flow by establishing a one-way circulation while prioritizing the implementation of a bike lane, as seen in Figure 16. Both streets have a width of 12.50 meters, suggesting significant potential for improving connectivity in the area.

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Figure 16. Proposal for the reconfiguration of J.M. Pedraza Street
Source: Project archive, 2023

The decision to establish a one-way circulation aims to streamline vehicular traffic, reduce possible congestion, and enhance transport efficiency in the area. At the same time, the integration of a bike lane represents a focus on promoting more sustainable modes of transportation, encouraging the use of bicycles as a viable alternative for urban mobility.

It is crucial to clarify that the connection with various streets leading to the historic center and major shopping centers highlights the strategic importance of these interventions to improve accessibility and connectivity in the heart of Huichapan.

The implementation of the proposed redesign of existing roads aims to prioritize users who travel with non-motorized vehicles and/or on foot. The Figure 17 presents roadway proposals for the El Saucillo - San José Atlán stretch.

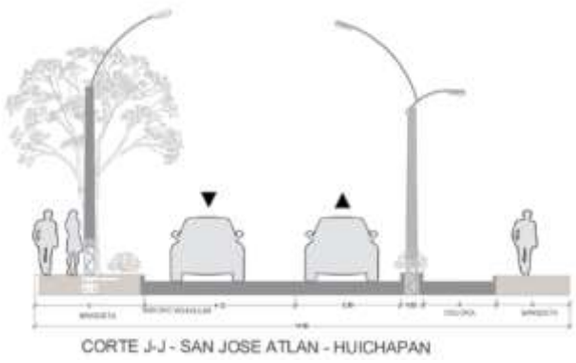

Figure 17 Proposed redesign of existing roads for the San José Atlán - Huichapan stretch
Source: Project archive, 2023

The representation in Figure 17 shows a prototype redesign of existing roads, prioritizing pedestrians and cyclists who use them. Figure 18 shows the proposed design for the El Saucillo - San José Atlán stretch.

Figure 18 Proposed redesign of the main road stretches El Saucillo - San José Atlán
Source: Project archive, 2023

In addition, as part of social integration and the enjoyment of public spaces, the implementation of secondary activities such as cultural events, reading points, sports activities, and recreational areas is suggested.

Organizing activities in public spaces, especially around bike lane areas where there are rest points, contributes to cultural enrichment. This not only improves the quality of life for residents but also strengthens their sense of community belonging. Figures 19-21 showcase renderings of the proposed urban image of the lanes and the integration with suggested rest nodes.

Figure 19 View of the bike lane San José Atlán - Huichapan
Source: Project archive, 2023

Figure 20 View of the bike lane San José Atlán - El Saucillo
Source: Project archive, 2023

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Figure 21 Integration of rest nodes
Source: Project archive, 2023

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Conclusions

It is worth reaffirming that the implementation of a route connecting neighboring rural communities through a bike lane encourages people to engage in healthy and ecological activities, allowing them to interact in society. It is important to note that one of the parameters for measuring the quality of life of human settlements is the aspect of mobility within their communities, as it is a crucial factor for generating economic benefits and thereby improving the well-being of the population.

Sustainable mobility not only has environmental benefits by reducing greenhouse gas emissions to improve air quality, but the design of urban infrastructure that favors both pedestrians and cyclists encourages people to opt for active modes of transportation. This, in turn, improves their health, promotes regular physical activity, leading to improved public health outcomes, and a reduction in cardiovascular diseases such as diabetes and hypertension, which require special care in old age.

Hence, the significance of addressing the issue from a sustainable perspective. According to the Ministry of Health of Mexico, "physical activity is one of the pillars of a healthy life: weight is kept under control, the risk of developing diabetes, hypertension, some types of cancer, and other chronic diseases is reduced... cycling improves physical fitness, respiratory health, and heart health" (2018).

It is important to highlight that the design of the bike lane was established according to the topographic patterns of the surrounding communities, focusing on the economic and social needs of the population of Huichapan Hidalgo. It presents itself as an alternative to current and, in some cases, obsolete mobility systems. It enables the promotion of urban improvement toward a resilient city with competitive mobility, providing citizens with safe, comfortable, accessible, affordable, and sustainable transportation options. Furthermore, it promotes physical activity and prioritizes the reduction in the use of hydrocarbons, contributing to the fulfillment of Goal 9 of the United Nations 2030 Agenda, "Industry, innovation, and infrastructure. The goal is to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation" (IMCO, 2020).

As Huichapan is part of the designation of "Magical Towns" registered with the Ministry of Tourism and possesses an area of Historical Monuments by the INAH, the design of this bike lane allows for the enhancement of the public image of the area, with minimal alteration to its current appearance. Having the aforementioned designations implies that its urban-rural image should not be significantly altered.

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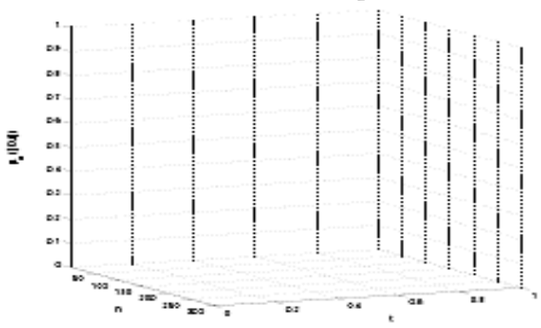

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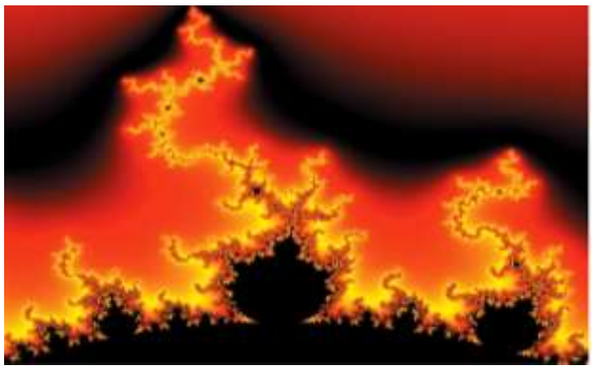

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