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Journal Civil Engineering

Definition of Journal

Scientific Objectives

Support the international scientific community in its written production Science, Technology and Innovation in the Field of Engineering and Technology, in Subdisciplines Bridge construction, development of environmental engineering, management in housing construction, hydraulic infrastructure, soil mechanics, sanitary engineering, road infrastructure.

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Journal Civil Engineering is a Journal edited by ECORFAN-Mexico, S.C. in its Holding with repository in Republic of Peru, is a scientific publication arbitrated and indexed with semester periods. It supports a wide range of contents that are evaluated by academic peers by the Double-Blind method, around subjects related to the theory and practice of Bridge construction, development of environmental engineering, management in housing construction, hydraulic infrastructure, soil mechanics, sanitary engineering, road infrastructure with diverse approaches and perspectives, that contribute to the diffusion of the development of Science Technology and Innovation that allow the arguments related to the decision making and influence in the formulation of international policies in the Field of Engineering and Technology. The editorial horizon of ECORFAN-Mexico® extends beyond the academy and integrates other segments of research and analysis outside the scope, if they meet the requirements of rigorous argumentative and scientific, as well as addressing issues of general and current interest of the International Scientific Society.

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Instructions for Scientific, Technological and Innovation Publication

Knowledge Area

The works must be unpublished and refer to topics of Bridge construction, development of environmental engineering, management in housing construction, hydraulic infrastructure, soil mechanics, sanitary engineering, road infrastructure and other topics related to Engineering and Technology.

Presentation of Content

In the Issue 20, as first article we present *Adaptation of the infrastructure of the university cafeteria [Nevería], Faculty of Engineering of the Autonomous University of Campeche – Campus V* by Yx-Sonda, Andrés, Flores-Chinchilla, Mariela, May-Tzuc, Oscar and Barrera-Lao, Francisco, with adscription in Universidad Autónoma de Campeche, as the next article we present, *Physical-mechanical characterization of the limestone rocks of the Mary Carmen Bank in Seybaplaya, Campeche, Mexico: Implications for the construction and conservation of built heritage* by Naal-Pech, José Wilber, Palemón-Arcos, Leonardo, El-Hamzaoui, Youness and Paat- Estrella, Josefa de los Ángeles, with adscription in Universidad Autónoma del Carmen and Universidad Autónoma de Campeche, as the next article we present, *Design of flush toilets using local materials in vulnerable areas of Altamira, Tamaulipas* by Martínez-Flores, Hilario Rafael, Alarcón-Ruiz, Erika, Zamudio-Aguilar, Minerva Ana María and Ordóñez Pacheco, Luis Daniel., with adscription in Tecnológico Nacional de México - Campus Ciudad Madero, as the next article we present, *Development and hygrothermal analysis of an optimized composite ecological construction material for semi.arid condictions: a case study in derramadero, Coahuila* by Vázquez-Aguilar, Mario Leonardo, Díaz-Silvestre, Sergio Enrique, Correa-Vázquez, Evanivaldo and Chávez-González, Alexis Daniel, with adscription in Universidad Tecnológica de Saltillo, as the next article we present, *Characterization, generation of orthophotos, and mapping of tree cover within an educational environment* by Palacios-Hernández, Otoniel & Moreno-Martínez, Viridiana, with adscription in Universidad de Guanajuato, as the last article we present, *Influence of stress state on volumetric behaviour of soils* by Arroyo, Hiram, Palos-Barba, Viviana and Chávez-Cárdenas, Xavier, with adscription in Universidad de Guanajuato and Autonomous University of Queretaro.

Content

Journal Civil Engineering 9[20]1-11: e1920111
Article

Adaptation of the infrastructure of the university cafeteria [Nevería], Faculty of Engineering of the Autonomous University of Campeche – Campus V

Adecuación de la infraestructura del comedor universitario [Nevería], Facultad de Ingeniería de la Universidad Autónoma de Campeche – Campus V

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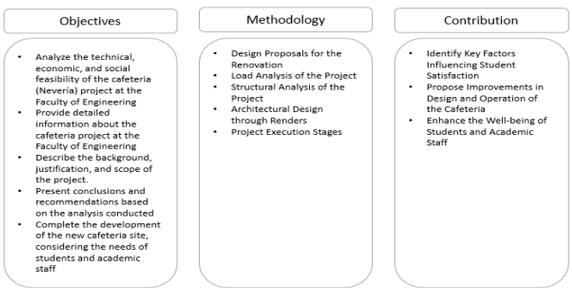
Abstract

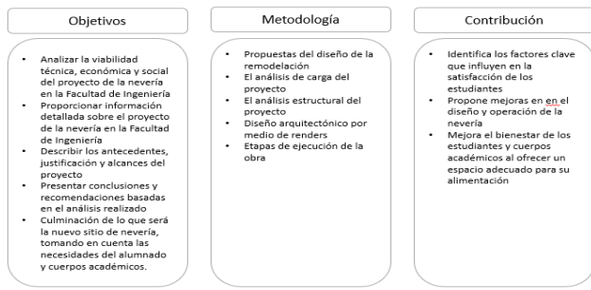
The article discusses the suitability of the cafeteria in the V Campus of the Faculty of Engineering at the Autonomous University of Campeche. It highlights the importance of properly conditioning common areas in higher education institutions, as these spaces are essential for recreation, relaxation, and food consumption by students, academics, administrative staff, and visitors. The document addresses the diagnosis and analysis needed to improve these areas, with the goal of creating an optimal and functional environment within the campus.



Common spaces, university infrastructure, student well-being.

Resumen

El artículo trata sobre la adecuación de la nevería en el Campus V de la Facultad de Ingeniería de la Universidad Autónoma de Campeche. Se destaca la importancia de acondicionar adecuadamente las áreas comunes en instituciones de educación superior, ya que estos espacios son esenciales para el esparcimiento, la recreación y la ingesta de alimentos de estudiantes, académicos, administrativos y visitantes. El documento aborda el diagnóstico y el análisis necesarios para mejorar estas áreas, con el objetivo de crear un entorno óptimo y funcional dentro del campus.



Espacios comunes, infraestructura universitaria, bienestar estudiantil

Area: Advocacy and attention to national problems

Citation: Yx-Sonda, Andrés, Flores-Chinchilla, Mariela, May-Tzuc, Oscar and Barrera-Lao, Francisco. [2025]. Adaptation of the infrastructure of the university cafeteria [Nevería], Faculty of Engineering of the Autonomous University of Campeche – Campus V. Journal Civil Engineering. 9[20]1-11: e1920111.

Introduction

Institutions of higher education are the places where students in professional training spend most of their time outside their homes. They are also spaces where a large number of individuals—such as faculty members, administrative staff, and occasional visitors—interact. Therefore, for academic entities such as the Faculty of Engineering at the Autonomous University of Campeche [Campus V], it is essential to have adequately conditioned common-use areas for recreation, leisure, and food consumption. Consequently, conducting detailed studies of these areas allows us to gain a general overview for decision-making, with the aim of developing an immediate adaptation plan that will help us ensure optimal conditions in the spaces designated for such purposes. The main advantage of preparing a diagnostic assessment for adaptation is that, when done in a timely manner, it helps extend the infrastructure's lifespan, better withstand the high impact of school space occupancy levels, and—above all—enhance user safety. This aligns with broader quality assurance models in higher education, such as those proposed by Ferrari Arroyo & Gallegos Muñoz [2025], where infrastructure adaptation forms part of continuous improvement actions to meet accreditation standards.

In the specific case of the Faculty of Engineering at the Autonomous University of Campeche, the institution is subject to ongoing evaluations to ensure the quality of its academic programs. It is accredited by organizations such as the Inter-Institutional Committees for the Evaluation of Higher Education [CIEES], the Accreditation Council for Engineering Education [CACEI], among others. As part of the periodic reviews conducted by these accrediting bodies, visits have been made to Campus V to assess all essential aspects required for ensuring quality education. These include teacher training, faculty profiles, the number and academic rank of faculty members, as well as classroom and laboratory equipment, and campus infrastructure, among other elements.

From these visits, the most recent evaluation carried out by CIEES in 2021 identified the university cafeteria—commonly known as "La Nevería"—as one of the areas with potential for improvement.

This was due to the fact that it is an open-air space and is significantly affected by various climatic factors of the region, which impact its comfort and usability. The evaluation committee explicitly recommended that the necessary modifications be made to this common area to meet minimum requirements. This implies a redesign of the space to address its current shortcomings. Similar to institutional strategies adopted in other Latin American universities [Tauber, Delucchi, & Olivieri, 2025], this redesign seeks to address not only climatic exposure but also food safety and hygiene standards. Food safety, in particular, is a growing concern in public dining services and has been identified as a critical area of intervention in broader regional studies [Ramírez Montero, 2025].

Based on the above, the present work focuses on generating the necessary adaptations to the university cafeteria ["La Nevería"] of the Faculty of Engineering – Campus V, in accordance with the need to increase seating capacity and to establish a secure, enclosed structure that protects against climatic and hygienic factors. It also aims to respond to the recommendations made by accrediting bodies during evaluation visits. All these efforts are supported by structural and geotechnical studies to optimize the available space. This approach seeks to provide a comprehensive perspective that contributes to informed decision-making when planning or executing infrastructure adaptations at the Engineering Faculty.

Historical Background

The Faculty of Engineering was established in 1958, beginning with the Civil Engineering program, housed at the current Campus I. In 1998, due to the need to grow in accordance with the demands of the 21st century, the decision was made to construct new facilities and relocate the faculty to Campus V, where it has been located since July 20, 2011. Currently, the faculty offers six undergraduate programs: Civil Engineering and Management, Energy Engineering, Mechatronics Engineering, Computer Systems Engineering, Electromechanical Engineering, and Software Technology Engineering. It also offers two graduate programs: the Master's in Renewable Energy and Energy Efficiency and the Master's in Engineering with a focus on Road Infrastructure.

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Each year, an average of 350 students enroll in the Faculty of Engineering, distributed among the six undergraduate and two graduate programs.

The Faculty of Engineering holds various accreditations for its academic programs. The Computer Systems Engineering undergraduate program is accredited by CIEES, having been granted Level 1 for a period of five years, valid from June 2017 to July 2022. The Civil Engineering and Management program is also accredited by CIEES, with the same Level 1 distinction and validity period. The Mechatronics Engineering program is accredited by CACEI for five years, from December 2017 to December 2022. The Energy Engineering program is accredited by CACEI for three years, from December 2019 to December 2022. The Civil Engineering and Management program also received a separate five-year accreditation from CACEI, valid from February 2020 to February 2025.

The graduate programs hold recognition from the National Postgraduate System [Sistema Nacional de Posgrado, SNP], awarded by Mexico's Secretariat of Humanities, Science, and Technology [SECIHTI]. Additionally, the Faculty of Engineering maintains active membership in the National Association of Faculties and Schools of Engineering [ANFEI].

It is crucial for the Faculty of Engineering to maintain these accreditations in order to ensure that its academic programs meet nationally recognized quality standards. These accreditations support the pursuit of high-quality education and drive the institution to continually evaluate and improve its processes and programs. This commitment to continuous improvement benefits the entire academic community.

Social impact

To contribute to the improvement of common-use area infrastructure by creating a comfortable, functional, and suitable environment for students, faculty, and administrative staff. This will enhance the educational experience for students and provide an appropriate setting for visiting faculty and exchange students, as well as for the general public visiting the facilities of the Faculty of Engineering at the Autonomous University of Campeche [Campus V].

Case study description

The adaptation study was conducted at the facilities of CAMPUS V [Faculty of Engineering], located in the northeastern part of the city of San Francisco de Campeche, in the Ex-Hacienda Kalá neighborhood [19.8456° N, 90.4774° W], covering an area of 39,949.19 m². Figure 1 illustrates the spatial layout of the Faculty of Engineering facilities, where the architectural plan begins with a concentric organizational core represented by Building A, aligned along a north–south axis defined by Building B. From this axis, Buildings E and F extend westward, and Buildings C and D extend eastward in a staggered arrangement, with the main entrance serving as the pivot point.

Box 1

Figure 1
Layout Plans of the Faculty of Engineering
Source: Authos' own work

Within this complex, the university cafeteria known as La Nevería is located to the west of Buildings E and F, occupying a surface area of 183.83 m². An interior comfort adaptation is proposed for this space.

In its current condition, the cafeteria consists of a steel structure with a polycarbonate sheet roof, and its sides are open to the elements.

This configuration makes the space unsuitable for prolonged occupancy due to high temperatures and the intrusion of dust and debris carried by the wind.

Current state of the building

Currently, the cafeteria is comprised of a steel structure and a polycarbonate sheet roof [Figure 2].

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Polycarbonate, when exposed to UV light due to its molecular structure, undergoes degradation and becomes brittle over time. Similarly, part of the cafeteria is open to the elements on its sides, which prevents comfortable use of the space due to high temperatures, dust and debris carried by the wind, as well as heavy rains combined with strong winds, making the cafeteria unusable during certain times of the year.

Box 2

Figure 2

Current status of the building at the Faculty of Engineering

Source: Authors' own work

During the field visit to the existing university cafeteria, surveys were conducted to confirm the project dimensions and carry out the necessary adjustments. Observations were made for the proposed renovations, which include: maintenance of the masonry structure and concrete columns in the kitchen area [kitchen storage, service area, and breakfast room]; use of the existing building as structural support for the new construction; modification of the slab and the retaining wall to allow for the expansion of the university cafeteria; inclusion of special installations [such as the placement of solar panels on the roof] in the load analysis; consideration of a potential expansion of the building; and the proposal to apply the same structural system criteria used in the classrooms adjacent to the cafeteria.

Adaptation proposal

A rectangular-shaped space is proposed to optimize the distribution of service tables, using the same existing area and accommodating up to 60 consummers. A ceiling height of 3.6 m is considered to enhance thermal comfort, featuring a skylight for natural ventilation, oriented north to capture prevailing winds from that direction.

The integration of floor-to-beam window walls is also proposed to take advantage of cross ventilation during winter and to ensure natural lighting throughout the year [on the east and south sides].

On the west-facing side, a blind wall with small openings near the ceiling is proposed to allow natural extraction of warm air from space. On the east side, the façade design includes a cantilevered slab that covers more than 90% of the glass walls to help mitigate solar heat gain. On the south façade, a vertical green wall is planned to reduce solar radiation while also creating a refreshing ambiance through vertically arranged vegetation.

The interior layout includes a service counter where students can work with their electronic devices. The proposal also includes electrical outlets and voice and data service points. To ensure a comfortable environment, air conditioning vents with grilles are designed along the central axis of the cafeteria, as well as indirect lighting concealed within a false ceiling, adding dynamism to the interior design composition. The exterior design aligns with the overall minimalist architecture of the campus complex [Figure 3].

Box 3

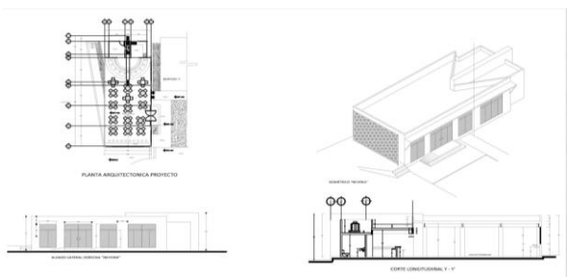

Figure 3

Architectural design proposal for the schoolar cafeteria

Source: Authors' own work

The energy department, having already obtained approval for the architectural plans, proceeded with the analysis of artificial lighting and environmental conditioning needs through vents and the air conditioning system. This included the development of calculation reports and the preparation of the corresponding technical drawings.

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Design criteria

The design was divided into two stages: [i] the first involved conducting the corresponding load analyses; [ii] the second involved performing the structural analysis. The structural project was governed by the following codes:

- Complementary Technical Standards on Criteria for Structural Design of Buildings. Official Gazette of Mexico City [2017a].

- Complementary Technical Standards for the Design and Construction of Concrete Structures. Official Gazette of Mexico City [2017b].

- Complementary Technical Standards for the Design and Construction of Masonry Structures. Official Gazette of Mexico City [2017c].

The design was complemented by local research literature on materials and construction procedures.

Structural load analysis

Two categories of loads were considered based on the duration during which they act on the structures at their maximum intensity: permanent loads and variable loads. The final use of the structure was taken into account to define the variable loads.

The combinations of DEAD LOAD + LIVE LOAD and DEAD LOAD + SELF-WEIGHT were used to check the Serviceability Limit States in accordance with the Complementary Technical Standards on Criteria and Actions for Structural Design of Buildings Official Gazette of Mexico City [2017a]..

The load analysis for the mezzanine is shown below [see Table 1], as well as the loads considered for the rooftop [see Table 2].

Box 4

Table 1

Mezzanine slab loads

Beam-and-block slab [12-5 beam and 15x25x56 block] Loads on mezzanine slab [kg/m²]	
Self-weight of slab with length = 4 m	291
Additional live load according to RECDMEX-2017	40
Installations	20
Ceiling finishes with 2 cm thickness	42
Mortar for ceramic tile bonding with 3 cm thickness	42
Ceramic tile floor	25
Partition walls and special installations	100
Total dead load	**560**
Live load according to NTC & DC. [2017a] [kg/m²]	**350**
Service loads	910
Amplified loads 1.3 x dead load + 1.5 x live load [kg/m²]	1253

Source: Authors' own work

Box 5

Table 2

Rooftop slab loads

Load on rooftop slab [kg/m²] Beam-and-block slab [12-5 beam and 15x25x56 cm block]	
Self-weight of slab with length = 4 m	291
Additional live load according to NTC & DC. [2017b]	40
Top finish of calcrete [filling and waterproofing]	264
Installations	20
Mortar ceiling	42
Total dead load	657
Live load according to NTCDMX 2017	100
Service load	767
Amplified loads 1.3 × dead load + 1.5 × live load	1004

For the mezzanine slab, it is proposed to use 12-5 beams with blocks measuring 15 cm x 25 cm x 56 cm, topped with a 5 cm thick compression layer. Table 1 details the specific loads calculated for the mezzanine, including the slab's weight and other elements, to ensure that the cafeteria is a safe and functional building.

For the rooftop slab, it is proposed to use 12-5 beams with blocks measuring 15 cm x 25 cm x 56 cm, also with a 5 cm thick compression layer.

Table 2 refers to the loads supported by the rooftop slab, which is located at the top of the building. It mentions the loads involved, as well as installations such as pipes or electrical systems that may be present.

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Table 3 helps to understand how much weight the mezzanine slab can support and how these loads are properly distributed, so the slab is not affected by factors such as the type of material, its thickness, or the way it is supported.

Box 6

Table 3

Rooftop slab loads

Mezzanine slab loads [kg/m²] Loads on mezzanine slab in reinforced concrete slab	
Self-weight of slab with length = 4 m	384
Additional live load according to NTC & DC. [2017c]	40
Installations	20
Ceiling finishes with 2 cm thickness	42
Mortar for ceramic tile bonding with 3 cm thickness	42
Ceramic tile floor	25
Partition walls and special installations	100
Total dead load	**653**
Live load according to NTCCDMX 2017 [kg/m²]	**350**
Service loads	1003
Amplified loads 1.3 × dead load + 1.5 × live load [kg/m²]	1373

Source: Authors' own work

To carry out all this design and calculation, it was essential to perform a structural analysis to ensure that the construction can withstand the loads without compromising its strength. Figure 4 highlights the area covered with a reinforced concrete slab; for this reason, the building will have two slab systems for construction purposes.

Box 7

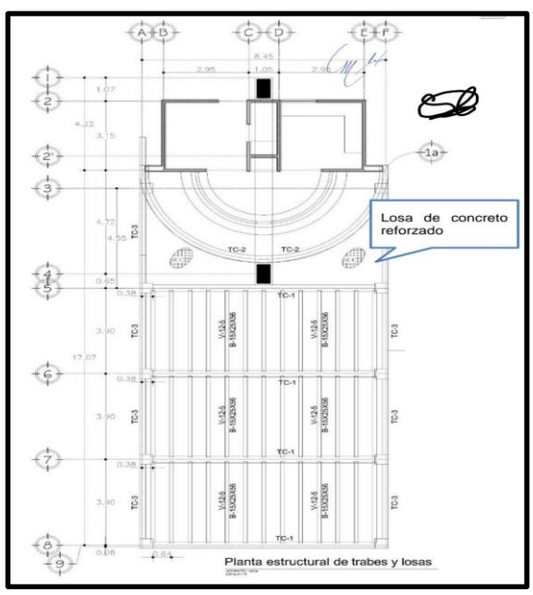

Figure 4

Structural plans of beams and slabs

Source: Authors' own work

Structural analysis for building improvement

Foundation

The bearing conditions of the supporting subsoil were determined based on previous geotechnical studies conducted near the site by a local company. These studies indicate an allowable bearing capacity of 20.0 Ton/m² at a depth of 1.50 m, from the natural ground level to the resistant stratum.

For the column loads, concentric spread footings type Z-1 made of reinforced concrete were designed, along with their respective foundation pedestals. These footings are connected by tie beams of type CT-1. These must include a leveling course built from hollow vibro-compacted concrete blocks, filled with concrete and reinforced with a 3/8" rebar embedded every 60 cm, plastered on both faces, and topped with a 15x30 cm foundation beam reinforced with four 3/8" rebars and ¼" stirrups every 15 cm [Macgregor, 1997].

For wall loads, continuous stone masonry footings are provided, topped with a 15x20 cm foundation beam reinforced with four 3/8" rebars and ¼" stirrups spaced every 15 cm. Additional requirements [González Cuevas, O., & Femández Villegas, F., 2013]:

- A 5 cm thick plain concrete blinding layer [f'c = 100 kg/cm²] must be provided under all footings to support the rebar framework.
- All reinforcement bars must be bent or hooked at their ends for proper anchorage.
- Rebars for columns and wall piers must be bent and tied to the main reinforcement of the footings.
- Reinforcement steel must be corrugated bars with a yield strength of fy = 4200 kg/cm² in the specified diameters.
- A minimum concrete cover of 5 cm must be maintained for all main reinforcement.
- All foundation elements must be waterproofed.
- The structural concrete for footings, pedestals, and foundation beams must have a compressive strength of f'c = 250 kg/cm² and should be poured dry.

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Slabs

For the foundation, roof and intermediate floor slabs are designed using precast prestressed concrete joists, type 12-5, combined with vibro-compacted hollow concrete blocks measuring 15 cm x 25 cm x 56 cm, both commercially available in the area. Specifications regarding depth and spacing indicated in the structural plans must be strictly followed. A 5 cm thick hydraulic concrete topping layer with a compressive strength of f'c = 200 kg/cm² is placed over the surface, reinforced with welded wire mesh 6-6/10-10 for thermal cracking control, with a minimum concrete cover of 1.5 cm.

Beams

The beams will carry the loads from the concrete slabs, for which three types of beams were designed: TC-1, TC-2, and TC-3. All beams shall be made of reinforced concrete with a compressive strength of 250 kg/cm².

Columns

The columns transfer the loads from the concrete beams. They are designed as type C-1 columns with dimensions of 45 cm x 45 cm, using hydraulic concrete.

The top of the columns must be level with the bottom face of the slab or beam to be supported. It is preferable to chip off a portion of the column for proper bearing of the beam or slab, rather than adding a segment during casting.

General Specifications

Regarding additional structural considerations: the spacing between reinforcement bars in structural elements must not be less than 1 inch. When parallel reinforcement is arranged in two or more layers, the bars must be aligned vertically with a minimum clear spacing of 1 inch between layers.

Anchorage hooks or bends must be formed cold, with a minimum length of twelve times the diameter of the bar, unless otherwise specified. Splicing and lap lengths must be at least forty times the bar diameter.

A pre-mixed permeable concrete blend was used to achieve uniform mixtures; in all cases, appropriate dosage for the design strengths must be ensured. Quality control of the concrete should be maintained by sampling for compressive strength testing at 7, 14, and 28 days.

For structural elements with cross-sections greater than 20 cm, a minimum concrete cover of 5 cm is required; for sections less than 20 cm, a minimum of 3 cm cover is required from the surface to the reinforcement. Mortars must have a mix proportion that ensures a minimum direct compressive strength of f'c = 40 kg/cm² at 28 days. The specifications above must be complemented by Official Gazette of Mexico City [2017a]. and the Construction Regulations for the Municipality of Campeche [Ayuntamiento de Campeche, 2015].

Architectural Design and Construction Process

The render prepared for the cafeteria renovation offers a clear and realistic vision of the project, highlighting its spaciousness and functionality [Figure 5]. With a design tailored to meet the needs of the large student population of the engineering faculty, the space is intended to be welcoming and efficient. The wide entrance and large windows ensure good natural lighting and ventilation, creating a comfortable environment. Additionally, the integration of solar panels reflects a commitment to sustainability, enabling more environmentally friendly operation of the facility. This not only benefits the environment but may also help reduce long-term operational costs.

The project focuses on creating a recreational space that invites students to enjoy pleasant moments. This place will not only serve as a food service area, but will also provide a comfortable space to rest and socialize with friends. Moreover, it addresses the need for shelter during hot or rainy days, ensuring the space remains functional under various weather conditions. With a cozy and attractive design, the project aims to foster community and student well-being, turning the cafeteria into a key meeting point for the faculty.

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Box 8

Figure 5
Rendered Design Proposal of the Building
Source: Authors' own work

Results

First Stage

Before beginning construction, it was essential to prepare the site to ensure a stable foundation. The existing structure was dismantled, and debris and objects that could affect the construction were removed [Figure 6]. The ground was leveled to prevent issues with unevenness in the foundation. Layout work was carried out, marking the exact location of walls and structural axes [Figure 7]. Trenches for the foundation were excavated according to the structural plans.

Box 9

Figure 6
Dismantling of Existing Structure
Source: Authors' own work

Box 10

Figure 7
Layout, Leveling, and Excavation for Adaptations
Source: Authors' own work

Box 11

Figure 8
Foundation
Source: Authors' own work

For this project, an allowable bearing capacity of 20 Ton/m² was specified for the supporting soil stratum, with a depth of 1.50 m from the natural ground level to the resistant layer.

Concentric footings of type Z-1 made of reinforced concrete were designed, along with their corresponding foundation pedestals [Figure 8].

These footings were connected by tie beams. Reinforcing steel was placed according to the structural plans, formwork was installed to contain the concrete, which was then poured and allowed to cure properly.

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Second Stage

Reinforced with rebar and concrete, beams and girders were installed to support the slab. The slab was assembled with reinforcing steel, formwork was placed, and concrete was poured. Ducts and pipes for electricity, water, and drainage were embedded in the walls and slabs [Figure 9].

Box 12

Figure 9

New structure of the building

Source: Authors' own work

After completing the structure, the finishes that provide both aesthetics and functionality to the building are carried out [Figure 10]. Layers of cement and sand are applied to the walls for a uniform finish. Ceramic flooring is installed, with coatings applied in the bathrooms and kitchen to protect against moisture. Door and window frames are installed in the required areas. A paint layer is applied to walls and ceilings, along with waterproofing of the roof to prevent water infiltration.

Box 13

Figure 10

Masonry Work and Facade Finishes of the Building

Source: Authors' own work

Third Stage

Once the finishes were completed, the building's functional systems were installed [Figure 11]. Switches, outlets, and lamps were installed through conduit piping, along with an electrical panel equipped with proper protections and connections. All wiring was concealed behind drywall panels mounted on an internal framework made of metal profiles. Installations were also made for the kitchen area, including piping for the stove and other gas appliances, potable water connections, as well as drainage and sewer lines. Cabinets were installed in the sink area.

Box 14

Figure 11

Electrical and Plumbing Installations in the Renovated Building

Source: Authors' own work

Conclusions

The development and execution of the adaptation project for the cafeteria at Campus V of the Faculty of Engineering have yielded substantial and measurable improvements, both in functional terms and in the quality of the built environment.

One of the most significant outcomes was the expansion of the usable area, which directly translated into an increased capacity to serve a greater number of users simultaneously. This improvement not only addresses a longstanding need within the faculty but also enhances the daily experience of students, who now benefit from a safer, more hygienic, and more pleasant space for dining and social interaction.

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From a technical perspective, the construction adhered strictly to the structural plans and local building regulations. Reinforced concrete footings, beams, and slabs were implemented using high-quality materials and following standardized procedures, ensuring the building's long-term structural stability. Every phase of construction—from site clearance and excavation to the placement of reinforcement, formwork, pouring of concrete, and controlled curing—was carefully supervised to comply with the required specifications and performance criteria.

The project also included essential finishes that contributed to both durability and aesthetics. Smooth plastering of walls, the installation of ceramic flooring and wall tiles, and high-quality waterproofing of the roof collectively enhanced the building's functionality and resilience to environmental conditions. Moreover, the integration of aluminum doors and windows, electrical and hydraulic systems, and gas and drainage lines was executed efficiently to ensure the comfort and safety of future users.

Architecturally, the cafeteria was designed with sustainability and user well-being in mind. The inclusion of large windows improves natural ventilation and lighting, while the installation of solar panels reflects a commitment to environmentally responsible design. These features not only reduce the ecological footprint of the facility but also align with global trends in sustainable construction and energy efficiency. In this regard, the project resonates with broader academic perspectives that emphasize the role of universities in promoting sustainability through their physical and educational environments. As highlighted in the case of the Universidad Católica de Manizales, the construction and adaptation of campus spaces must integrate academic, physical-spatial, and institutional dimensions to foster sustainable development in higher education institutions [Hernández-Araque, 2016].

Overall, the project met its objectives by delivering a high-quality, multi-functional space that reflects the academic and social values of the Faculty of Engineering. The cafeteria now stands as a vital communal space where students can gather, relax, and recharge.

Additionally, the building was structurally prepared for potential future vertical expansion, demonstrating foresight and adaptability in its design. This project is a clear example of how thoughtful planning and professional execution can significantly enhance the campus infrastructure, contributing to a better educational environment.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Yx-Sonda, Andrés: was responsible for drafting the manuscript and preparing the technical reports related to each construction phase.

Flores-Chinchilla, Mariela: contributed to the writing of the original version of the manuscript and documented the project through photographic records.

May-Tzuc, Oscar: collaborated in the writing of the final version of the manuscript and participated in the development of the methodological framework.

Cruz y Cruz, Andrea del Rosario: supervised the overall project development and verified the accuracy and execution of structural calculations.

Barrera-Lao, Francisco Javier: served as the project leader and principal investigator, overseeing the initiative and securing the necessary funding for its implementation.

Availability of data and materials

The structural and architectural plans used in the project are available upon request from the Faculty of Engineering at the Autonomous University of Campeche. Photographic records and construction reports were generated directly by the project team and are available from the corresponding author upon reasonable request.

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Article

Physical-mechanical characterization of the limestone rocks of the Mary Carmen Bank in Seybaplaya, Campeche, Mexico: Implications for the construction and conservation of built heritage

Caracterización físico-mecánica de las rocas calizas del banco Mary Carmen en Seybaplaya, Campeche-México: Implicaciones para la construcción y conservación del patrimonio edificado

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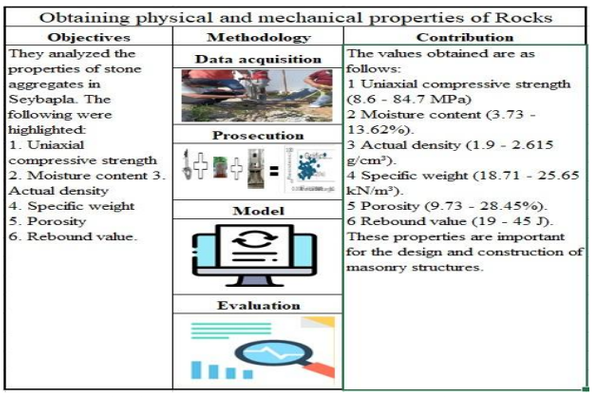
Abstract

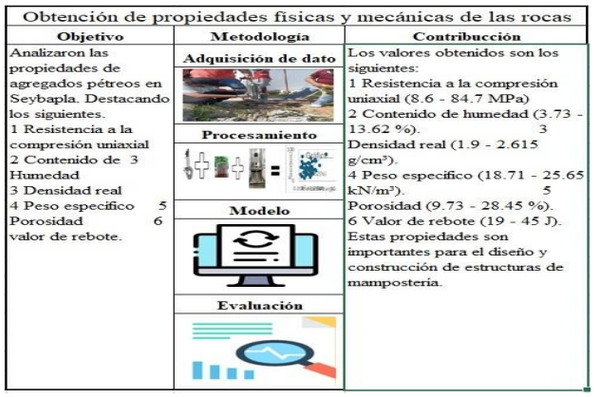
The properties of rock aggregates in Seybaplaya, Campeche, Mexico were analyzed, highlighting their uniaxial compressive strength [8.6 - 84.7 MPa], moisture content [3.73 - 13.62 %], real density [1.9 - 2.615 g/cm³], specific weight [18.71 - 25.65 kN/m³], porosity [9.73 - 28.45 %], and rebound value [19 - 45 J], emphasizing the importance of these properties for the design and construction of masonry structures.



Simple uniaxial compressive strength, Moisture content, True density, Porosity and surface area in rocks

Resumen

Se analizaron las propiedades de agregados pétreos en Seybaplaya, Campeche, México, destacando su resistencia a la compresión uniaxial [8.6 - 84.7 MPa], contenido de humedad [3.73 - 13.62 %], densidad real [1.9 - 2.615 g/cm³], peso específico [18.71 - 25.65 kN/m³], porosidad [9.73 - 28.45 %] y valor de rebote [19 - 45 J], lo que resalta la importancia de estas propiedades para el diseño y construcción de estructuras de mampostería.



Resistencia a la compresión uniaxial simple, Contenido de humedad, Densidad real, Porosidad y área superficial en roca

Area: Dissemination and universal access to science

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Introduction

Rocks are formed by hard, compact natural aggregates composed of mineral particles bound together by strong permanent cohesive bonds, making them generally continuous systems. The proportion of minerals, granular structure, texture and origin of the rock are key characteristics used in its geological classification [González, 2002]. All built heritage stands on soil or rock, and every construction project requires the use of stone aggregates, with rocks being the essential raw material for this purpose. It is therefore crucial to take their characteristics into account, as they are fundamental to ensuring structural stability and durability from the foundations up [Naal-Pech, 2023]. In the Yucatan Peninsula, the predominant rock material is limestone, which is inexpensive to extract and has physical and mechanical properties that make it an excellent building material. However, limestone is subject to chemical and physical alterations that can modify both its external appearance and its mechanical behaviour [Espinosa-Morales, 2021].

Rock blocks often show structural weaknesses, such as fractures, fissures, joints, discontinuities, and faults of various sizes, known as joints. It should be noted that virtually all the rocks that make up the kilometres of the Earth's crust have short fissures and cracks [Iriondo, 2006].

The diversity of structures, rock types and their spatial distribution have a considerable impact on the structural damage that can affect built heritage. It is therefore essential to identify these phenomena in a preventive manner, adapt land use according to the level of impact and reduce the vulnerability of buildings. This approach seeks not only to protect built heritage, but also to ensure the sustainability of buildings in complex geological contexts. In terms of size, rock aggregates are classified into two main categories: fine aggregates and coarse aggregates. Fine aggregates are composed of sand, either natural or manufactured, with particle sizes ranging from 60 µm to 5 mm. Coarse aggregates, on the other hand, include particles ranging in size from 5 mm to 125 mm [Neville, 1999]. Among the most relevant physical properties of aggregates are particle shape and texture, porosity, absorption, density, adhesion, and strength, among others.

In addition, the particle size distribution and maximum aggregate size, as in the case of gravel, are crucial factors that influence both the behaviour of concrete in its plastic state and in its hardened state. In tests carried out with concrete specimens made with limestone aggregates from the Yucatan Peninsula, it has been observed that failure occurs predominantly in the aggregates, especially when relatively low water/cement ratios [less than 0.5] are used. In addition to aggregate strength, other characteristics such as size, shape, surface texture and mineralogy also have a significant impact on concrete strength, although to varying degrees [Ezeldin & Aitcin, 1991].

Knowing the distribution of rock banks is essential to facilitate their grouping and subsequent characterisation, assigning mechanical behaviour parameters obtained through tests on representative samples. Among these parameters, the simple uniaxial compressive strength [SUC] of a rock is of particular importance, as it allows it to be classified mechanically. This value is key in the application of the most commonly used failure criteria in geotechnical engineering [Delgado, 2013].

In the state of Campeche, there is an important built heritage of Baroque architecture constructed with limestone masonry. These buildings are exposed to the humid tropical climate of the region, which causes differential alterations in the materials due to weathering. It is therefore essential to determine the properties and characteristics of the stone materials used, as this knowledge is key to their conservation, restoration and proper use in construction applications.

Study area

Seybaplaya, Campeche, is located in the geological region known as the 'Yucatan Platform', an extensive sedimentary rock formation, composed predominantly of limestone and clay, which covers much of the Yucatan Peninsula in Mexico.

This platform was formed millions of years ago due to the accumulation of marine sediments and has an approximate depth of 200 metres.

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It is particularly relevant to analyse the properties of the rocks from the bank located in Seybaplaya, known as 'Mary Carmen', as well as its surroundings, due to their extensive exploitation for construction materials. Figure 1 provides a visual reference of the area.

Box 1

Figure 1

Seybaplaya rock bank location in Campeche state, Mexico

The material bank is located in the Payucán region, with specific UTM coordinates of X: 741570.00 and Y: 2174740.00. The type of material available at this deposit is tezontle, with an estimated volume of 500,000 m³ [equivalent to 500 x 1000 m³]. The thickness of the overburden is 0.2 metres. There are no restrictions on the use of explosives at this deposit, which facilitates its exploitation. Furthermore, from an economic point of view, the extraction of the material is considered economically viable.

Methodology

Deposit exploration

The deposit known as Mary Carmen is of great importance due to its geographical location near the deep-water port of API Seybaplaya, as its stone aggregates can be exported to other states in Mexico or to other countries by sea. This rock deposit produces stone aggregates of various sizes for the construction of buildings or for designing asphalt for roads.

Sample size

In research where the main variable is qualitative and is reported as the proportion of the phenomenon studied in the reference population, the sample size is calculated using the following equation, which is used for an infinite population [i.e., when the total number of observation units that comprise it is unknown or when the population exceeds 10,000 units].

$$n = \frac{{z_\propto}^2 * p * q}{e^2} \quad [1]$$

Where.

n= SAMPLE SIZE
Z_α= statistical parameter depending on the confidence level
e= maximum estimated maximum estimated error
p= probability of occurrence of the event under study [success]
q= [1-p] is the probability that the estimated event does not occur

To determine the number of samples in this research, the analysis was conducted as follows: since the event under study is unknown and considered infinite, proportions of p = 50% and q = 50% were assumed, implying equal probability of occurrence or non-occurrence. A 90% confidence level was used [Zα = 1.645] and a margin of error of e= 12 [https://www.fisterra.com/formacion/metodologia-investigacion/determinacion-tamanomuestral/]

$$n = \frac{1.645^2 * 50 * 50}{12^2} = 46.979$$

Therefore, 50 samples were established for the study.

For sample collection, 5 points were located at sites where the bench had been dynamited, the coordinates of which are presented in Table 1. Figures 2 and 3 show the rock bank named Mary Carmen where the samples were taken.

Box 2

Table 1

Location of simples

Sample Range	Coordinates UTM [X, Y]
Samples 1 to 10	[741595, 2174717]
Samples 11 to 20	[741611, 2174838]
Samples 21 to 30	[741585, 2174851]
Samples 31 to 40	[741591, 2174750]
Samples 41 to 50	[741605, 2174803]

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Box 3

Figure 2
Geographical location of sampling points.

Box 4

Figure 3
Rock bench "Mary Carmen".

2.2 Sample extraction and preparation

The preparation of rock core samples and the evaluation of their dimensions and shape, in accordance with the provisions of ASTM D4543-12 [2012]. This standard specifies that samples must be straight circular cylinders and strictly comply with the established tolerances.

The main requirements include the following:

1. Length-to-diameter ratio: length and diameter between 2.0 and 2.5.
2. Minimum diameter mm.
3. End surfaces: The ends of the cylinders must be polished to a flat surface with a maximum tolerance of 0.001 inches.

These criteria ensure uniformity and precision in the tests carried out on the samples [Figure 4].

Box 5

Figure 4
Samples in the form of a straight circular cylinder

In order to evaluate the rock properties of the "Mary Carmen" bench, the following sequence of tests was designed.

2.3 Resistance to simple uniaxial compression [RCUS]

The uniaxial compression test was carried out in accordance with ASTM D7012-10. The method used to calculate the uniaxial compressive stress is equal to the axial load divided by the cross-sectional area..

$$\sigma=\text{RCUS}=\frac{P}{A} \quad [2]$$

Where:
σ = RCUS = simple uniaxial compressive strength
P = Axial load
A = Cross-sectional area

2.3.1 Procedure for simple compression test, on the universal machine model 2000 and Serial No.: 011065

1. Recorded the dimensions to assess the cross-sectional area.
2. Checked that the universal machine is set correctly [at zero].
3. The specimen was placed in the centre of the compression platens of the universal machine [Figure 5].
4. Using the control software to program the machine and run the compression test, the load was applied in a gradual manner.

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5. The test was carried out until failure of the specimen revealed cracks [Figure 6].
6. Finally, the specimen was removed from the machine and a new specimen was placed, repeating the procedure described above. [Nieto & Avendaño, 2015]

Box 6

Figure 5

Position of the specimen in the centre of the compression platens of the universal machine

Box 7

Figure 6

Compressive strength test

2.4 Water content

2.4.1 Current moisture content

This value is a key indicator of the water accumulated in the aggregate, influenced by factors such as bank conditions, ambient humidity and the presence of interconnected pores, among others.

The objective of this test is to determine the moisture content present in a rock in its natural state, as indicated in the standard. [ASTM 2010b D2216-10].

2.4.2 Calculation of moisture content.

Moisture content was calculated using equation 3, which relates the wet weight and dry weight of the samples.

$$\%\ Current\ Humidity = \frac{p_i - p_f}{p_f} \text{x} 100 \qquad [3]$$

Where:
Pi= Initial sample weight, g.
Pf= Final weight of the sample, g.
An average of the representative rock samples is determined.

2.5 Procedure for determining the water content in rock

1. Preparation of the sample.
2. Initial weighing [wet weight].
3. Oven drying: Set the oven temperature to 105 ± 5 °C. For 24 hours.
4. Final weighing [dry weight].
5. Calculation of water content.
6. Results.

2.4.4 Actual density test

The actual density test on rock was carried out in accordance with ASTM D 854. This test is used to calculate the actual density of rocks, which represents the ratio of the actual mass of the sample to its actual volume. The value of this parameter was calculated using the equation 4:

$$\gamma = \frac{m}{V} \qquad [4]$$

Where
ɣ = the actual density
m = the mass of the rock
V = the total volume of the sample.

Procedure for determining the true density in rock

- Determine the value of the mass of the sample in grams.
- Determine the volume of the sample in
- Divide the mass by the volume cm

2.6 Specific gravity test

The rock specific gravity test is performed following the guidelines established in ASTM D 854.

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The purpose of this procedure is to determine the real density of the rocks, which is defined as the ratio between the real mass of the sample and its real volume.

Once the density is obtained, the specific weight of the rock is calculated by multiplying it by the acceleration of gravity. This parameter is fundamental to characterise the physical properties of the material.

The calculation of the value of these parameters is done using specific equations, as detailed in the density [4] and specific weight [5] equations.

$$P=\gamma g \quad [5]$$

Where:

1. ɣ = the actual density
2. g = gravity
3. P = specific gravity.
4. Procedure for determining the specific gravity in rock

Once the true density has been determined, the true density is divided by the gravity.

2.7 Porosity

ASTM D4404 establishes the standard procedure for calculating porosity in rocks, which is carried out by the following equation:

$$Poros\ \% = \frac{Vol.\ de\ poros}{Vol.\ total}\ x\ 100 \quad [6]$$

Where:

Pore volume = volume of water absorbed by the rock sample.
Total vol. = total volume of the rock sample..

2.7.1 Procédure de détermination du pourcentage de pores dans la roche

1. Sample preparation
2. Dry weight measurement
3. Saturation of the sample
4. Measurement of the saturated weight
5. Determination of total volume
6. Calculation of pore volume
7. Calculation of porosity

2.8 Surface hardness [sclerometry]

The procedure established by the field index test according to USBR [1998] requires ten readings at different points on each analysed surface. Subsequently, the five lowest values are discarded and the average of the five highest values is calculated, thus obtaining a representative result.

In this case, given that the hammer available is of type N [designed for concrete] and what is required is a hammer of type L [specific for rock], the correlation equation proposed by Poole & Farmer [1980] is used, which allows the results obtained with the hammer of type N to be adjusted to estimate values equivalent to the type L. The correlation equations include specific considerations for the position of the hammer, either horizontal or vertical downwards, and are designed to minimise the standard error [eσ] associated with the estimation of the values [equation 7].

$$R=1{,}838+0{,}813RN;e\sigma=2{,}9 \quad [7]$$

Where:
RN= rebound value of concrete type hammer
R V= rebound value already correlated to the rock type.

2.7.2 Procedure for using the Schmidt hammer in rock

1. Preparation of the test area
2. Verification of the Schmidt hammer
3. Positioning of the hammer
4. Conducting the test
5. Recording of data
6. Calculation of the average
7. Conversion of rebound rate to resistance

3 Results

Tests were carried out on 50 samples of 5.08 cm [2 in] diameter and with a length ratio of 2-2.5 times the diameter. The results of compressive strength in Mpa, moisture content in %, actual density in g/cm3, specific gravity x 103 in N/m3, porosity in %, and rebound value [Table 2] were obtained.] [Naal-Pech et al., 2023].

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Box 8

Table 2

Table 2 Results of 50 samples.

ID	RCUS [MPa]	Water content [%]	Actual Density [g/cm^3]	Specific gravity [kN/m^3]	Porosity [%]	Rebound value [J]
1	31.6	7.79	2.07	20.2969	16.12	30
2	28.6	7.08	2.37	23.2406	16.77	36
3	46.8	7.09	2.38	23.3416	16.87	27
4	15.2	9.24	2.26	22.1972	20.90	31
5	18.3	8.43	2.24	22.0139	18.93	29
6	11.7	6.96	2.32	22.7956	16.16	35
7	22.7	8.01	2.24	21.9463	17.92	33
8	42.1	5.98	2.38	23.3876	14.25	19
9	53.4	5.79	2.42	23.7025	13.98	38
10	14.9	11.25	2.15	21.0619	*24.15*	30
11	68.6	7.49	2.34	22.9992	17.57	32
12	8.6	9.19	1.91	18.7118	17.52	32
13	23.2	6.31	2.30	22.5369	14.49	22
14	40.7	6.72	2.34	22.9663	15.74	38
15	43.5	3.96	2.50	24.4967	*9.88*	20
16	28.7	4.19	2.48	24.3683	10.41	40
17	43.6	7.50	2.29	22.4521	17.17	30
18	55.5	4.28	2.58	25.2793	11.03	42
19	32.3	8.00	2.29	22.4442	18.30	37
20	61.3	5.71	2.43	23.8702	13.89	43
21	78	4.51	2.51	24.5744	11.30	40
22	61.9	6.20	2.40	23.5791	14.90	36
23	42.4	4.23	2.55	25.0202	10.80	44
24	49.1	11.32	2.11	20.6647	23.85	37
25	84.7	5.80	2.52	24.748	14.64	44
26	72.8	5.38	2.46	24.1366	13.23	34
27	38.1	4.31	2.56	25.1228	11.04	29
28	33.2	7.22	2.29	22.4872	16.55	34
29	58	7.24	2.26	22.1556	16.34	31
30	23.9	5.49	2.42	23.6929	13.27	43
31	21.3	7.57	2.27	22.2322	17.16	28
32	40	6.14	2.27	22.2586	13.93	35
33	34.8	5.94	2.39	23.4224	14.18	33
34	43.6	6.02	2.27	22.2384	13.64	32
35	18.5	6.27	2.30	22.5979	14.44	39
36	54.1	7.29	2.24	22.0043	16.35	40
37	45.5	8.03	2.25	22.0671	18.06	27
38	44.1	12.66	2.04	20.0185	25.84	36
39	22.4	6.69	2.27	22.2381	15.16	35
40	35.1	4.39	2.47	24.1842	10.81	27
41	43.4	13.62	2.09	20.4987	28.46	31
42	37.4	5.39	2.46	24.1049	13.25	36
43	31	4.27	2.48	24.3428	10.59	39
44	36.5	3.73	2.61	25.5866	9.73	40
45	63.7	4.08	2.56	25.0749	10.43	43
46	15.7	11.82	2.18	21.3591	25.73	37
47	57.6	4.74	2.58	25.3142	12.22	33
48	40.5	4.97	2.40	23.5603	11.94	35
49	65.1	5.09	2.50	24.5425	12.74	45
50	23.3	3.95	2.62	25.6597	10.32	41

3.1 Physical-mechanical parameter ranges:

Table 3 shows the ranges of values of the different physico-mechanical parameters of the rock samples included in the study.

Box 9

Table 3

Range of values of RCUS, Moisture content, % porosity, True density and Surface hardness, True density [g/cm^3] in rock samples from the Seybaplaya bench.

Concept	Rango	Mean value	Standard deviation
RCUS in [MPa]	8.6 <> 84.7	40.14	17.99
Water content [%]	3.7313<>13.62	6.706	2.34
Actual density [g/cm3]	1.9<>2.615	2.351	0.159
Specific gravity [x103 in N/m3]	18.712<>25.66	23.07	1.56
Porosity [%]	9.7321<>28.46	15.45	4.38
Rebound Value [RV]	19<>45	34.6	6.13

4. Discussion

4.1 Rock sample extraction and preparation process:

For the exploitation of the bench, explosives were used, and large rock fragments were randomly selected to obtain representative samples. During the extraction phase, it was observed that the drilling rate varied according to the hardness of the rocks, which was confirmed by compression tests and the identification of the samples through their respective IDs. In addition, when water was injected into the drill hole, a white liquid was generated, indicating the presence of limestone in the rocks. The observed characteristics are indicative of the heterogeneity of the material.

The studies of the properties of the Yucatan limestone rock, carried out by Lauro A. Alonzo Salomon and Leopoldo Espinosa Graham are shown in Table 4 provided shows the values of standard deviation, mean and coefficient of variation for four properties of the limestone rock: volumetric weight, strength, density and absorption. The meaning of the values and their interpretation is explained below:

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Box 10

Table 4

Values of the coefficient of variation.

Property	Standard Deviation [σ]	Media [μ]	Coefficient of Variation [CV]
Volumetric weight [g/cm³]	0.3769	2.1102	17.86 %
Resistance [Kg/cm²]	161.1550	282.6708	57.01 %
Density [Ss]	0.3525	2.1707	16.24 %
Absorption [%]	7.0257	7.1125	323.66 %

4.2 Sample preparation

The collected samples were measured with a Vernier caliper, and cross-sections were made to adjust them to the required dimensions. However, in some cases, the process was complicated due to the disintegration of the samples, which prevented compliance with the required dimensional ratio of 2 to 2.5 times the diameter. This made it necessary to drill new samples to meet the established requirements.

Once prepared, the samples were subjected to drying and humidification processes in the materials laboratory in order to achieve the optimum moisture content and drying level for subsequent testing.

4.3 Simple uniaxial compressive strength

For this test, it was very important to polish the cross section so that when the load was applied, it complied with the required standard and was distributed evenly throughout the sample. Table 3 shows a very significant dispersion between the samples of this mechanical property, generated by heterogeneity and sampling conditions. It is important to consider these parameters in the design of cementitious base materials in order to obtain the best durability conditions.

4.4 Moisture content

There is a very significant dispersion between the samples with respect to moisture content, which is important for determining the recommended amount of water for designing concrete and/or mortar.

4.5 Actual density

There is significant dispersion among the samples with respect to actual density. These data are important for selecting the location of that sample and selecting the points where there is greater resistance in the bench, thus enabling the design of better resistances.

4.6 Specific weight

There is a very significant dispersion among the samples with respect to specific weight. This data is important for selecting the location of that sample and selecting the points where there is greater resistance in the bench, thus designing better resistances. It can also be confirmed that specific weight is closely related to density.

4.7 Porosity

There is a very significant dispersion among the samples with respect to porosity. It was observed that there are rock fragments with very large pores ranging from 0.5 cm, which affects the compressive strength of the samples and, therefore, their dispersion.

4.8 Rebound value

For this test, rock fragments and a concrete sclerometer were used. Before measurement, the surfaces were polished to remove irregularities.

The following was observed:

- Higher polishing speeds were associated with smoother surfaces.
- Greater difficulty in polishing indicated greater hardness in the rock.

During the polishing process, the rocks gave off a whitish dust, characteristic of limestone, confirming once again its composition.

Conclusions

The findings presented show significant progress in the field of rock mechanics in the state of Campeche. The data obtained and analysed in this document provide a clearer picture for understanding the behaviour of local rocks, which is key to the construction, rehabilitation and/or conservation of the region's built heritage. The main conclusions are highlighted below.

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5.1 Applications in construction and rehabilitation

The information obtained from the aggregates from this rock bank is relevant for the design of mixtures and blocks for the construction of confined masonry walls and low walls, as well as perimeter walls for the reconstruction, rehabilitation and conservation of the built heritage. It is expected that the blocks produced will meet the necessary structural requirements, achieving an average strength of **f´c = 3.92 MPa [40 kg/cm²]**.

5.2 Strength of stone aggregates

The results of the compression tests on these rocks show an average strength of **40.14 MPa [409.31 kg/cm²]**. However, due to the characteristics of the materials available in the region, it is not possible to manufacture high-strength concrete for the built heritage. The maximum concrete strength achieved in the region is **f´c = 29.42 MPa [300 kg/cm²]**.

This information allows appropriate decisions to be made for the design and execution of construction and/or rehabilitation projects for historic structures.

The aggregates from the rock bank studied meet the necessary characteristics for use in the restoration and conservation of the facades of the historic centre of San Francisco de Campeche, as they are very similar.

Declarations

Conflict of interest

The authors and co-authors declare that they have no conflicts of interest. They have no competing financial interests or personal relationships that could influence the content of this article.

Contribution of the authors

Naal-Pech, José Wilber: Contributed significantly to the conceptualisation of the project, as well as to the development of the research method and technique. He supported the design of the field instrument and carried out the data analysis, systematising the results. He was also responsible for writing the article.

Palemón-Arcos, Leonardo: Carried out the background research for this article and provided support in the design of the field instrument. He also contributed to the writing of the article.

El-Hamzaoui, Youness: Contributed to data processing and the generation of tables of contents and their analysis, as well as to the development of the approach, method and writing of the article.

Paat-Estrella, Josefa de los Ángeles: Contributed to the research design, defining the type and approach of the study, as well as the development of the method and the writing of the article.

Availability of data and materials.

The data obtained from this research are available for consultation at any time as needed.

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Abreviaturas

ASTM American Society for Testing and Materials.

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RCUS Compressive Strength Uniaxially Simple Compressive Strength.

R V= Rebound value already correlated for rock type.

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Article

Design of flush toilets using local materials in vulnerable areas of Altamira, Tamaulipas

Diseño de letrinas con arrastre hidráulico utilizando materiales locales en zonas vulnerables de Altamira, Tamaulipas

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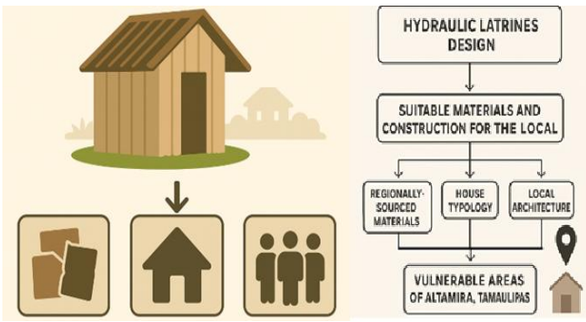
Abstract

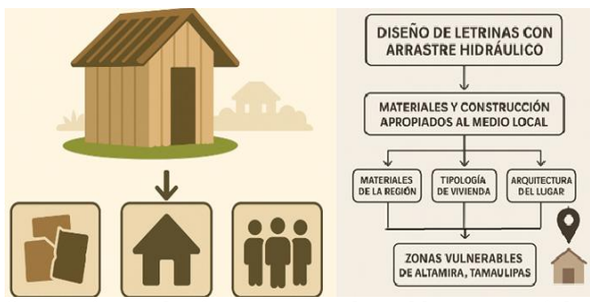
This research paper presents the design of hydraulically flushed latrines that use local materials for the construction of the huts, ensuring that the sanitation system blends harmoniously with the physical and cultural environment of rural or peri-urban communities. Based on the premise that user acceptance increases when sanitation solutions respect the building typology, local resources, and social customs, we propose a technically, environmentally, and socioculturally viable model that promotes sustainability and improved basic sanitation conditions.



Sanitation, latrine, vulnerable areas, local materials

Resumen

El presente trabajo de investigación presenta el diseño de letrinas con arrastre hidráulico que emplean materiales locales para la construcción de la caseta, de manera que el sistema sanitario se integre armónicamente con el entorno físico y cultural de las comunidades rurales o periurbanas. Bajo la premisa de que la aceptación del usuario aumenta cuando las soluciones sanitarias respetan la tipología constructiva, los recursos locales y las costumbres sociales, se propone un modelo técnico, ambiental y socioculturalmente viable que promueva la sostenibilidad y la mejora en las condiciones de saneamiento básico.



Saneamiento, letrina, zonas vulnerables, materiales locales

Area: Dissemination and universal access to science

Citation: Martínez-Flores, Hilario Rafael, Alarcón-Ruiz, Erika, Zamudio-Aguilar, Minerva Ana María and Ordóñez Pacheco, Luis Daniel. [2025]. Design of flush toilets using local materials in vulnerable areas of Altamira, Tamaulipas. Journal Civil Engineering. 9[20]1-5: e3920105.

1. Introduction

In rural and marginalised areas of Mexico and Latin America, access to adequate sanitation services remains limited. Despite institutional efforts to introduce low-cost technologies such as dry or flush toilets, many projects fail due to a lack of social acceptance or because they are not adapted to local conditions. The availability of water resources is conditioned by precipitation, evaporation and water quality. In Tamaulipas, during 2024, an unprecedented water crisis was faced, with challenges such as the contamination of surface and groundwater bodies due to the discharge of untreated domestic effluents. This problem is particularly serious in rural communities in the southern part of the state, where a significant portion of the population lacks access to drainage and drinking water systems, resorting to the use of latrines, which violate the water table.

This work is based on the hypothesis that aesthetic, cultural and functional harmony between the latrine and the local dwelling improves its use, maintenance and community ownership. To this end, a design is proposed that makes use of local materials [wood, brick, stone, palm, adobe, etc.], preserves the architectural identity and uses an efficient hydraulic system with minimal water consumption.

2. Objectives

The proposed objective is to design a model of a flush toilet that uses local materials and is accepted by the community as it integrates with the construction typology of the dwellings.

To this end, the following specific objectives were set:

- Identify the construction materials available in the area and assess their technical and environmental suitability.
- Propose a functional, safe and low-cost structural and sanitary design.
- Evaluate the community's perception and acceptance of the proposed model.
- Analyse the environmental and social benefits of using local materials and harmonious designs.

3. Flush toilet

Water-flush latrines are sanitation systems that use a small amount of water [between 1 and 3 litres] to transport waste to a septic tank or absorption pit. They represent an intermediate alternative between dry latrines and conventional toilets, combining low water consumption with greater comfort and odour control.

3.1 Importance of sociocultural context in design

Various studies on rural sanitation [WHO, 2019; CONAGUA, 2022] highlight that the success of a sanitation system depends both on its technical functionality and its social acceptance. When the latrine harmonises with local materials, colours and construction styles, users perceive it as part of their home, not as a foreign element.

3.2 Local materials and sustainability

The use of local materials reduces transport costs, carbon emissions and dependence on external inputs. It also boosts the local economy and facilitates maintenance, as the materials are familiar to users.

4. Methodology

4.1. Study area

The research was conducted in rural communities in southern Tamaulipas [Mexico], where housing is predominantly made of natural materials [wood, brick, palm and rustic concrete], with a hot and humid climate and limited water availability.

Box 1

Figure 1

Study Area

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According to the INEGI 2020 population and housing census and random physical checks, drainage coverage is estimated to be 96% in Altamira, 91% in Ciudad Madero, and 99.4% in Tampico. This equates to a total of 31,085 people without drainage services in a regional population of 772,685 inhabitants: Altamira [269,190], Tampico [297,562] and Ciudad Madero [205,933].

This analysis reveals the urgent need to implement technical and policy strategies to reduce gaps in access to drainage systems, improving water quality, reducing health risks, and promoting sustainable water resource management in rural communities in the southern region of Tamaulipas.

4.2. Research stages

A flush toilet is a sanitary system that uses water to remove human waste. It is connected to an absorption well through pipes and has a siphon that prevents bad odours and insects from entering. To adapt a flush toilet, a lid can be installed on the slab covering the hole. The cover can be made of wood and operated with a pedal. Plastic slabs with a self-sealing system can also be installed.

Flush toilets are a sustainable option that helps prevent groundwater and surface water contamination. Some advantages of flush toilets are: They do not generate odours or flies, they are cheaper than tank toilets, they allow grey water to be reused, and they prevent the waste of clean water. The proposed research stages are detailed below:

1. Participatory diagnosis: interviews and workshops with residents to learn about habits, aesthetic preferences and available materials.

2. Technical analysis: evaluation of the strength, durability, permeability, and cost of local materials.

3. Structural and sanitary design: preparation of plans and a functional model of the flush toilet.

4. Community validation: presentation of the prototype to families to obtain feedback and gauge acceptance.

5. Results

The latrine design presented is conventional and standardised for most Latin American countries [Surco R., 2017]. The design proposal to be developed in this project aims to contribute to comfort and widespread use by modifying the construction elements with local materials and ergonomic designs for the average sizes of the rural population of southern Tamaulipas.

The improvements in the implemented design are detailed below [Figure 2]:

Box 2

Figure 2

Proposed design

Shed: wooden or adobe block structure with palm or sheet roofing, depending on availability.

Cladding: natural materials [lime or mud-based paints] that blend in with the colour of the houses.

Toilet: low-consumption toilet connected to a ventilated septic tank.

Ventilation and natural lighting: high windows and ventilation pipes to prevent unpleasant odours.

Estimated cost: between 25 and 40% less than a commercial latrine.

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On the other hand, the community showed a greater willingness to use latrines that 'resemble their homes,' both for aesthetic reasons and for safety and privacy. Local participation in the design increased the sense of belonging and commitment to maintenance, highlighting that the traditional approach to sanitary design, focused solely on technical functionality, neglected to consider social appropriation. Undoubtedly, incorporating cultural and aesthetic criteria into sanitary engineering was key to achieving solutions that can be durable and truly accepted by community residents. Furthermore, the integration of local materials is not only environmentally sustainable, but also reinforces the cultural identity and social appropriation of the project. Likewise, the use of low water consumption technologies allows for a transition to more sustainable systems in regions with water stress.

6. Conclusion

Flush toilets can be an effective, sustainable, and culturally accepted sanitation solution if they are designed based on local materials, styles, and needs. User acceptance depends directly on the visual and functional harmony of the toilet with its living environment. Community participation in all stages of design ensures the social sustainability of the project. This approach can be replicated in other regions of the country with adaptations according to climate, materials, and local culture.

Below are some recommendations:

- Conduct training programmes in self-construction with local materials.
- Implement pilot projects that integrate participatory design criteria.
- Promote public policies that encourage the use of culturally appropriate sanitation technologies.
- Evaluate the life cycle of materials to optimise environmental impact.

The main characteristics of the materials considered are their availability as raw materials in the ecosystem, their ability to withstand outdoor conditions, their ease of disposal, the fact that their extraction does not have a significant impact on the environment, and their affordable cost.

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Contribution of the authors

Martínez-Flores, Hilario Rafael: Contribution of the project idea, research on the method and technique.

Alarcón-Ruíz, Erika: Contextual study of the study area, responsible for citizen participation activities.

Zamudio-Aguilar, Ana: Analysis of the technical and regulatory capacity of the latrine proposal.

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Journal Civil Engineering 9[20]1-6: e4920106
Article

Development and hygrothermal analysis of an optimized composite ecological construction material for semi.arid condictions: a case study in derramadero, Coahuila

Desarrollo y análisis de un material higrotérmico de un material de construcción ecológico compuesto, optimizado para condiciones semi-áridas: caso de estudio en derramadero, Coahuila

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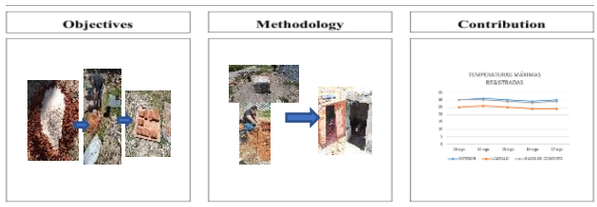
Abstract

This article analyzes the ecological, sustainable, and thermally efficient advantages of adobe brick as a construction material in the rural and semi-arid region of Derramadero in Saltillo, Coahuila. The study is based on the use of endemic materials and the revaluation of traditional building techniques employed for centuries, but currently rejected due to their association with poverty or obsolescence. As noted by Guerrero [2007], earthen architecture possesses widely recognized ecological and cultural qualities, although its application has declined in contemporary society. This work presents the thermal efficiency of an ecological adobe brick made with clay, manure, and silica sand, whose addition enhances the insulating and stabilizing effect of the product. The results show that the modified adobe contributes to thermal comfort in local housing, representing a viable, accessible, and sustainable alternative to the widespread use of concrete blocks.

Adobe brick, thermal efficiency, sustainable construction

Resumen

El presente artículo analiza las ventajas ecológicas, sustentables y térmicamente eficientes del adobe de barro como material de construcción en la región rural y semiárida de Derramadero en Saltillo, Coahuila. El estudio se fundamenta en el aprovechamiento de materiales endémicos y en la revaloración de técnicas constructivas tradicionales utilizadas durante siglos, pero que en la actualidad son rechazadas por asociarse a pobreza u obsolescencia. Tal como lo señala Guerrero [2007], la arquitectura térrea posee cualidades ecológicas y culturales ampliamente reconocidas, aunque su uso ha disminuido en la sociedad contemporánea. En este trabajo se expone la eficiencia térmica de un tabique ecológico elaborado con barro, estiércol y arena sílica, cuya adición permite mejorar el efecto aislante y estabilizante del producto. Los resultados muestran que el adobe modificado contribuye al confort térmico en viviendas de la zona, representando una alternativa viable, accesible y sustentable frente al uso generalizado del block de concreto.



Adobe de barro, eficiencia térmica, construcción sustentable

Area: Dissemination and universal access to science

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Introduction

The use of earthen materials such as adobe has been an ancestral practice in Mexico, especially in indigenous communities of Mesoamerica and arid regions where stone or industrialized resources were limited. Its application has been documented since pre-Hispanic times [Gama-Castro, 2012] and has endured through techniques such as adobe, rammed earth, and bahareque, due to its accessibility and thermal insulation capacity [Barahona, 1969].

In recent years, there has been renewed interest in soil-based construction, motivated by global trends toward sustainability, reduction of embodied carbon, and ecological architecture [Villagómez, 2021]. Research reviews highlight that earthen materials often outperform conventional construction materials in environmental indicators when local soil, minimal external binders, and low energy in preparation are used [Zhang, 2024]. The technical viability of stabilizing soil constructions—through mechanical, chemical, or hybrid additives—is also increasingly documented [Ravindran, 2023].

These techniques of improvement are analogous to the proposed method in this study, which uses silica sand as an additive to amplify the insulating and stabilizing properties of adobe. In Latin America there are studies, as in Rivera-Salcedo [2021] which demonstrates that the addition of coarse sand and vegetal fibers significantly improves compressive strength and water absorption properties in adobe masonry units.

Coahuila, and particularly the region of Derramadero, presents an arid to semi-arid climate, with extreme summer temperatures exceeding 35 °C during the hottest months [Secretaría de Medio Ambiente, 2023]. These conditions make thermal comfort strongly dependent on the construction material employed. In contrast, many Latin American countries, informal urban settlements continue to expand along city outskirts, where self-built construction remains the main pathway to home ownership. Nations such as Peru, Bolivia, and Mexico exhibit a significant proportion of dwellings erected without technical assistance or regulatory control, resulting in serious shortcomings in housing quality and comfort.

This issue is even more pronounced in high-altitude areas, where cold and humid climates require specific construction adaptations that are often absent. [Delgado Salazar, 2025]

This research proposes a hybrid adobe brick, made of clay mixed with manure and *silica sand*, which does not require direct-fire baking. This design seeks to improve the thermal insulation and stabilization properties of traditional adobe, becoming a viable, accessible, and sustainable alternative to the widespread use of concrete blocks in Derramadero.

Methodology

For the experimental design, ecological adobe bricks were manufactured using locally available raw materials. The mixture was prepared with the following proportions: 60% red clay soil from the Derramadero region, 20% cattle manure containing crushed corn stalks [*carrizo de milpa*], 10% water, and 10% silica sand [figure 1]. The inclusion of silica sand was intended to enhance thermal insulation and stabilize the composite. The mixture was homogenized manually until a uniform consistency was achieved.

Box 1

Figure 1
Material used
Source [Authors made]

Subsequently, the material was molded into rectangular units measuring 18 cm in width, 25 cm in height, and 2.5 cm in thickness [figure 2]. The specimens were left to set under direct sunlight for two hours, followed by controlled drying in an electric oven [NOVATECH, model HS35-A1A] at 180 °C for three hours [figure 3].

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This process ensured the elimination of excess moisture without direct firing, maintaining the ecological nature of the material.

Box 2

Figure 2
Molding bricks
Source [Authors made]

In order to evaluate the thermal efficiency of the proposed adobe brick, a comparative analysis was conducted against conventional concrete block construction. For this purpose, two scaled-down housing models were built, simulating the structural layout of a typical dwelling in the region.

Concrete block model**:** Constructed with 15 × 20 × 40 cm blocks joined with a traditional cement-sand mortar, and topped with a lightweight reinforced concrete roof. The dimensions of the model were 95 cm [length] × 90 cm [width] × 64 cm [height].

Box 3

Figure 4
Dried bricks
Source [Authors made]

Box 4

Figure 4
Concrete and bricks house scale model
Source [Authors made]

Bricks model: Built with the proposed hybrid adobe bricks, with final dimensions of 76 cm [width] × 91 cm [length] × 60 cm [height].

Both models were exposed under the same environmental conditions during the hottest season of the year [figure 4]. According to meteorological forecasts from AccuWeather, the period from August 13 to 17, 2025, corresponded to one of the warmest weeks in Derramadero, with maximum daily temperatures between 20 to 31 °C.

Temperature data were recorded inside each model for five consecutive days using memory-registering digital thermometers [UNI-T, model UT330C]. One device was placed in the center of each structure, which was subsequently sealed to avoid external airflow interference. The recorded data allowed the comparison of the diurnal thermal performance between the adobe and concrete block models [figure 5].

Box 5

Figure 5
Thermometers inside scale models
Source [Authors made]

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Results

The comparative thermal evaluation revealed a consistent difference of approximately 4 °C between the maximum interior temperatures of the adobe and concrete block models. While the interior of the adobe structure remained below the outdoor maximum values, the concrete block model exhibited interior temperatures nearly identical to those of the external environment, demonstrating poor thermal insulation capacity. This result highlights the superior thermal buffering effect of the adobe mixture, which effectively delayed and attenuated heat transfer [figure 6].

Box 6

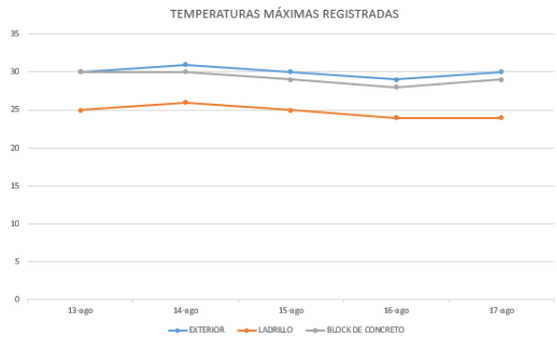

Figure 6
Temperature Comparative graphic
Source [Authors made]

Furthermore, qualitative observations during the testing period indicated that the adobe structure maintained more stable nocturnal temperatures, avoiding abrupt heat loss. In contrast, the concrete block model experienced rapid cooling, reflecting its limited thermal mass behavior.

In addition to thermal performance, permeability characterization was conducted on representative adobe samples to assess moisture absorption and vapor transmission. Techniques such as **capillary water absorption tests** and **vapor permeability measurements** were considered, given their relevance in evaluating construction materials exposed to semi-arid climates like Derramadero. The results indicated that the inclusion of silica sand in the adobe mix contributed to reduced capillary uptake, enhancing dimensional stability under humid conditions. This improvement is critical because high permeability can negatively affect the thermal resistance of earthen materials by facilitating heat transfer through absorbed moisture.

Overall, the findings support the notion that the optimized adobe mixture not only provides superior thermal insulation compared to conventional concrete blocks but also demonstrates improved resistance to environmental factors, thus reinforcing its potential as a sustainable construction material for hot and dry climates.

Development of permeability characterization

As an additional characterization step, the permeability of the adobe–silica brick was evaluated through a **capillary water absorption test**. The evaluation was based on the conceptual framework of **Darcy's law**, expressed as:

$$Q = -K \cdot A \cdot L\Delta h \quad [1]$$

Q = volumetric flow rate [m³/s],
K = permeability coefficient [m/s],
A = cross-sectional area of the sample [m²],
Δh\Delta hΔh = hydraulic head difference [m],
L = length of the sample [m].

In the experimental procedure, a brick specimen was placed in a container where a constant water flow was applied to one of its surfaces. The quantity of water absorbed was recorded over time. Knowing the applied flow rate, the exposed surface area, and the effective length of the sample, the permeability coefficient was calculated.

This approach allowed the characterization of the brick's capillary transport properties, which are crucial in semi-arid climates such as Derramadero, where cyclic wetting and drying can compromise the long-term durability and thermal efficiency of earthen materials [Ma, 2020].

The capillary absorption test indicated that the moisture front required **31 minutes and 58 seconds** to travel across the entire length of the brick specimen, reaching the opposite end.

Characterization Results

This relatively low absorption velocity reflects the contribution of the silica sand additive, which reduces pore connectivity and water uptake compared to traditional adobe [figure 7].

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Box 7

Figure 7
Permeability test
Source [Authors made]

These results are consistent with previous studies that highlight how the incorporation of stabilizing agents—such as manure and siliceous additives—can improve the moisture resistance of adobe by reducing permeability and enhancing mechanical stability [Sánchez-Calvillo, 2024]. The outcome suggests that the hybrid adobe–silica brick not only improves thermal insulation but also mitigates the main durability limitation of conventional earthen materials: excessive capillary water absorption.

Conclusions

This research demonstrates that adobe-based bricks, when modified with organic and mineral additives, can provide a viable, sustainable, and thermally efficient alternative to conventional concrete blocks [Sánchez, 2012] in semi-arid regions such as Derramadero, Coahuila. The experimental results showed **a temperature difference of up to 4 °C** between the interior of the hybrid adobe model and the concrete block model, highlighting the superior insulating capacity of the proposed material.

Furthermore, the **capillary absorption test** confirmed that the addition of silica sand and manure with vegetal fibers reduced permeability and moisture uptake, addressing one of the main durability limitations of traditional adobe. By improving thermal insulation and lowering water absorption, the hybrid brick combines the ecological advantages of earthen construction with enhanced performance for modern applications.

The findings reinforce the potential of **reintroducing earthen techniques** adapted with contemporary stabilization methods as a countermeasure to climate change, rising energy costs, and housing shortages in rural and peri-urban communities. Future research should extend these results by evaluating **mechanical strength, long-term durability, and scalability** for mass construction.

In conclusion, this work positions the hybrid adobe–silica brick as an accessible and environmentally responsible building material, bridging ancestral knowledge with modern engineering to promote sustainable housing in semi-arid regions.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Vazquez-Aguilar, Mario Leonardo: Contributed to the project idea, investigation, prototypes fabrication, writing –original draft and editing.

Diaz-Silvestre, Sergio Enrique: Contributed to execute permeability test and construction of house scale models

Correa-Vazquez, Evanivaldo: Contributed to the materials analysis and investigation.

Chavez-Gonzalez, Alexis Daniel: Contributed to assist design and fabrication activities.

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Journal Civil Engineering 9[20]1-8: e5920108
Article

Characterization, generation of orthophotos, and mapping of tree cover within an educational environment

Caracterización, generación de ortofotografías y plano del componente arbóreo dentro de un entorno educativo

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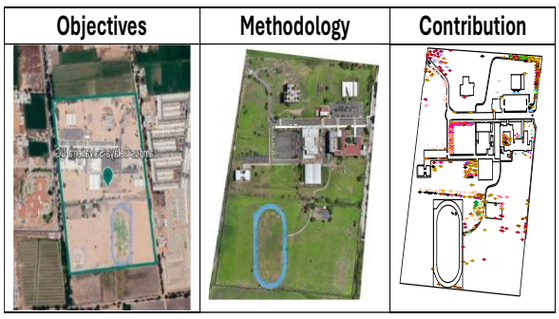
Abstract

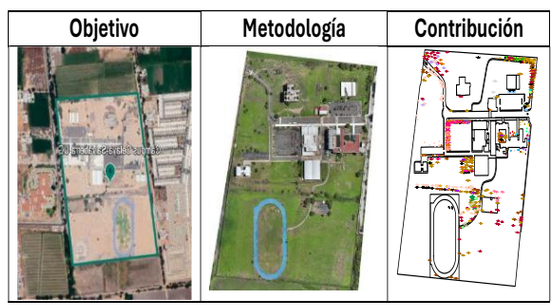
This research aims to quantify and characterize the tree assets of the Juan Pablo II site on the Celaya-Salvatierra Campus of the University of Guanajuato. It identified 559 trees, 75 species, and 34 families, detailing each tree's condition, sun exposure, and trunk diameter. A two-dimensional map was generated, locating the trees by family and drawing contour lines. This information allows for evaluations and decision-making regarding maintenance, reforestation, future growth, and sustainable land-use management for the area. The goal is to prevent the displacement of vegetation due to urbanization.



Urban trees, Sustainability, Orthophotography.

Resumen

La investigación busca cuantificar y caracterizar los activos arbóreos de la Sede Juan Pablo II del Campus Celaya-Salvatierra de la Universidad de Guanajuato, identificando 559 ejemplares efectivos, 75 especies y 34 familias familia, se detalló la condición del árbol, exposición al Sol y diámetro del tronco. Se generó un plano en dos dimensiones ubicando los ejemplares por familias, así como dibujando las curvas de nivel. Esta información permite realizar evaluaciones y toma de decisiones en términos de mantenimiento, reforestación, crecimiento a futuro y la gestión sostenible del uso del suelo para el espacio en cuestión. Con el objetivo de que se evite el desplazamiento del componente vegetal a causa de la urbanización.



Arbolado urbano, sustentabilidad, ortofotografía.

Area: Dissemination and universal access to science

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Introduction

The rapid growth of cities has led to urban trees being replaced by urban development, giving way to changes in land use that are not compatible with the conservation of vegetation. This displacement of vegetation cover brings about unfavourable changes in the environmental conditions of cities and, consequently, in the quality of life of their residents. By the end of 2022, around 56% of the world's population [4.4 billion people] will live in cities. This trend is expected to continue, with the urban population more than doubling by 2050, when almost 7 out of 10 people will live in cities [World Bank, 2022]. But vegetation is essential for the life of all species inhabiting the Earth, especially trees, as they produce oxygen, purify the air, form fertile soils, prevent erosion, keep rivers clean, capture water for aquifers, serve as shelters for wildlife, reduce soil temperature, encourage the establishment of other species, regenerate soil nutrients and improve the landscape [Ministry of Environment and Natural Resources, 2018]. Urban trees are generally located in public spaces and green areas such as parks, gardens or along city streets and medians, as well as in areas reserved for growth, which are becoming increasingly scarce. The University of Guanajuato has a significant environmental heritage, which is why there are constant efforts such as reforestation and preservation of the environment, particularly trees, at all its campuses, in line with the UN's Sustainable Development Goals. The study seeks to continue these actions by generating an inventory of the tree component and calculating the area of the Juan Pablo II Campus of the Celaya-Salvatierra Campus, beginning with mapping and surveying species and botanical families to obtain the distribution of trees on the land, monitoring at different periods during 2024 and 2025 due to the reforestation work carried out; aerial views were obtained with a drone to visualise the impact of the rainy and dry seasons on the tree component of the Campus. Locating and characterising the trees in the study area seeks to increase their visibility, leading to recognition of their real importance in the ecosystem services necessary for survival. It is essential that in cities with high levels of pollution, trees are allowed to survive regardless of changes in land use and the different economic activities to be carried out, as they can improve the quality of environmental conditions, making cities more suitable places to live.

Importance of urban trees

Talking about nature in the city is another challenge for sustainability, as urban ecology is significantly deteriorating due to increased urbanization [Galvez-Nieto, 2020], and trees are a key element in achieving urban sustainability.

The potential benefits of coexisting with trees in a given space are holistic. Environmentally, the strategic location of trees in cities can help cool the air by between 2 and 8 degrees Celsius. A mature evergreen tree, for example, can intercept more than 15,000 litres of water per year [ONU-Habitat, 2019]. socially, it creates more comfortable environments; some studies even suggest that the crime rate in certain cities in the United States of America is inversely proportional to urban tree cover [Pérez et al., 2024].

A mature tree can absorb up to 150 kilograms of polluting gases per year. As a result, trees play an important role in mitigating climate change [ONU-Habitat, 2019]. The presence of tree cover in large cities is key to reducing the concentration of CO_2 in the atmosphere. Urban areas are responsible for generating more than 80% of greenhouse gases [GHG] [Duval et al., 2023].

Therefore, a city with high green cover and a compact distribution of this vegetation has greater potential to store and sequester carbon. Urban trees capture suspended solid particles [PM_{10} or particles smaller than 10 microns] which adhere to the leaves and are washed away during rainy periods, thus carrying these particles into the sewerage system [Molina-Prieto y Vargas-Gómez, 2012].

Trees also have a dramatic influence on incoming solar radiation. In fact, they can reduce solar radiation by 90% or more. The radiation absorbed by the tree canopy leads to evapotranspiration, which lowers the temperature of the leaves, vegetation and air [Nowak et al., 1997].

In economic terms, improving the environmental quality of cities generates a social benefit for their inhabitants by raising their quality of life, and by raising the quality of life, the land is revalued, as these areas of the city acquire added value [Galindo-Bianconi y Victoria-Uribe, 2012].

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Characteristics of the study site

The study area is located on the grounds of the Juan Pablo II Campus of the Celaya-Salvatierra Campus of the University of Guanajuato, located at Ing. Javier Barros Sierra 201, CP. 38140, in the city of Celaya, the micro-location [Figure 1] and macro-location [Figure 2]. The municipality of Celaya is located between parallels 20° 42' and 20° 21' north latitude; meridians 100° 38' and 100° 56' west longitude; altitude between 1700 and 2700 m; the predominant soils are Vertisol [71.79%], Phaeozem [10.33%] and Leptosol [5.17%] [National Institute of Statistics and Geography, 2010]. It occupies 1.81% of the state's surface area. Its highest slopes range from 5 to 10 per cent. Celaya has a semi-dry, semi-warm climate [65%], sub-humid with lower humidity in summer [21%], semi-dry temperate [7.4%], temperate sub-humid with lower humidity in summer [4.5%] and temperate sub-humid with medium humidity in summer [2.1%]. Among its characteristics, it has a climate with an approximate temperature range of 6°C to 31°C [Official Gazette of the Federation, 2022]; the temperature peaks in August with a range between 26 and 34°C.

Box 1

Figure 1

Micro-location Juan Pablo II Headquarters, Celaya-Salvatierra Campus, UG (Google Earth, 2025)

Box 2

Figure 2

Micro-location Juan Pablo II Headquarters, Celaya-Salvatierra Campus, UG (Google Earth, 2025)

The average annual rainfall ranges between 600-800 mm [National Institute of Statistics and Geography, 2010]. The Celaya Valley aquifer is overexploited. This aquifer has an annual recharge of 286.6 Mm^3 [million cubic metres] per year; with an extraction volume of 593 Mm^3, groundwater is the main source of water supply and irrigation for crops in Celaya; The dynamic level in all wells averages 110 metres, but drilling is currently taking place in risk areas at depths of more than 600 metres to capture water in areas where there is no arsenic.

The municipality of Celaya is mainly a plain, with soils suitable for agriculture, urban development and other anthropogenic activities, which is why most of its natural cover has been transformed to make way for agriculture, pastures and urban areas [Municipal Institute of Research, Planning and Statistics of the Municipality of Celaya., 2023].

According to the analysis of information reported by the municipality's monitoring network, practically since the beginning of its operations, the main air quality problems in Celaya have been related to high concentrations of PM_{10} and environmental ozone [O_3]. Based on municipal reports, Celaya is one of the cities in Guanajuato with the most serious problems of PM_{10} pollution [Celaya Municipal Council, 2019].

The most important natural vegetation consists of oak forests, low deciduous forests, scrubland and grasslands, mainly comprising trees of the Bursera genus and other species such as Acacia spp., Opuntia spp., Myrtillocactus, and Mimosa spp., such as ahuehuetes [sabinos], huizaches, mesquites, pirules, sapotes, ash trees, willows, cazahuates [palos bobos], nopales, granjenos, tepeguajes, sicuas, tepames, nopal, and maguey [Celaya Municipal Council, 2019].

Most of the green areas in the municipality are complementary or linked to the road network [central and side medians; tree, shrub, and herbaceous vegetation in roundabouts]. There are also fragmented urban green areas [public planters and private gardens; parks, vacant lots, boulevards, and public and private academic institutions] [Municipal Institute of Research, Planning and Statistics of the Municipality of Celaya, 2014], such as the study area.

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Methodology

The entire Juan Pablo II campus of the Celaya-Salvatierra campus of the University of Guanajuato was georeferenced, delimiting the built-up, open and permeable areas, with particular attention to the location of the trees contained within the space. Altitude [elevation] data was collected from different points on the terrain and the location of those points [X, Y coordinates] for the contour lines. The survey was carried out with a drone, obtaining photogrammetric images.

The drone flew between 9:00 a.m. and 12:00 p.m. and/or between 3:00 p.m. and 5:00 p.m.; the time range was essential to avoid any shadows or interruptions in the visual line between the camera and the object to be reconstructed, as this constitutes an obstacle for the algorithm; Orthophotographs or orthoimages were taken at different times to determine the condition of the trees during the dry and rainy seasons.

It is stated that, during the use of the drone and the processing of this data, the privacy of the university community on campus was respected.

Subsequently, each of the tree specimens found at the Juan Pablo II site was located, quantified and characterised by species and botanical family. This process was carried out by a team on foot in the area, using chalk [completely washable] to mark the trees and label them, which would then be represented on the map.

The characterisation by species and family was carried out with the help of the Plant Palette of the Municipality of Celaya and other plant catalogues from similar geographical areas.

The following details were also recorded: tree condition [excellent, good, fair, poor, critical, dead], circumference [cm], sun exposure [full, partial, shade], distance to the nearest building [m] and direction to the nearest building.

Finally, a map of the Juan Pablo II headquarters was drawn up, showing all the families found in the area surveyed in both years, providing a graphical representation of the trees in the study area.

Results

Two orthophotographs were obtained from the drone flights, the first of which was taken during the dry season, when it is possible to see the vegetation in a dry state [Figure 3]. In contrast, during the rainy season, the entire area is green [Figure 4]. This provides an overview of the behaviour of plant species and their resilience.

Box 3

Figure 3

Orthophotograph of the Juan Pablo II Headquarters, taken during the dry season.

Own work.

Box 4

Figure 4

Orthophotograph of the Juan Pablo II Headquarters, taken during the dry season.

Own work.

The approximate area of the headquarters is 184,009.11 m². The maximum height above sea level at the headquarters is 1,751 metres and the lowest point is 1,749 metres, indicating a difference of 2 metres.

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This allows for surface runoff and the creation of a micro-catchment area for rainwater, and therefore an important absorption area, since the surrounding areas are impermeable, covered with rigid and flexible pavement. The contour lines can be seen in Figure 5.

Box 5

Figure 5

Contour lines John Paul II Headquarters
Own elaboration

A total of 75 botanical species were identified, for a total of 590 specimens, of which 31 could not be identified due to their condition, since at the time of data collection in the field, the tree had no foliage, which made correct identification difficult. Therefore, there are 559 effective trees. Table 1 breaks down the species, with Vachellia farnesiana I being the most abundant species.

Box 6

Table 1

Botanical species found at the John Paul II headquarters

	Scientific name	No.
1	Unknown	31
2	Senna corymbosa	8
3	Schinus areira L.	11
4	Schinus molle L.	47
5	Senna corymbosa	8
6	Cascabela thevetiodes [Kunth] Lippold	1
7	Plumeria rubra L.	30
8	Thevetia peruviana [Pers.] K. Schumann	3
9	Phoenix roebelenii	3
10	Jacaranda mimosifolia	17
11	Casuarina cunninghamiana	8
12	Euphorbia cotinifolia	3
13	Acacia saligna [Labill.] H. L. Wendl.	12
14	Delonix regia [Bojer ex Hook] Raf	19
15	Acacia shaffneri [S. Wats] F. J. Herm.	1
16	Acacia pennatula [Schldl. & Cham.] Benth	12
17	Prosopis laevigata [Humb. Et Bonpl. Ex. Wild.]	6
18	Prosopis glandulosa. Torr.	5
19	Albizia occidentalis T. S. Brandegee	1
20	Lysiloma divaricatum [Jacq.] MacBride	1
21	Leucaena esculenta [DC.] Benth	1
22	Umbellularia californica [Hook & Arn] Nutt.	1
23	Gossypium	1
24	Hibiscus rosa-sinensis	20
25	Ficus benjamina	7
26	Eucalyptus camaldulensis	3
27	Psidium guajava	1
28	Bougainvillea	57
29	Fraxinus uhdei. Wenzig.	25
30	Fraxinus americana L.	20
31	Rhaphiolepis bibas [Lour] Galasso & Banfi	1
32	Citrus x aurantium L.	3
33	Solanum aviculare	11
34	Albiza lebbeck L	20
35	Bauhini variegata	2
36	Bursera fagaroides	2
37	Carica papaya L.	1
38	Casimiroa edulis la llave	1
39	Leucaena leucocephala	2
40	Chilopsis linearis	2
41	Cissus verticia L.	1
42	Delonix regia	3
43	Dodonia viscosa jacq	6
44	Ficus microcarpa L. F	1
45	Ficus Retusa L.	4
46	Flaxinus Angustifolia Vahl	1
47	Fraxinus uhdei	1
48	Fraxinus velutina	13
49	Gutierreza sarothrae	1
50	Heptapleurum actinophynum	1
51	Lophostemon confertus	1
52	Manikara zapota	10
53	Melia azedarach L.	3
54	Olea europaea L.	17
55	Orcopanax nymphneitolious	1
56	Parkinsonia aculeada	8
57	Piptadenia goanacatha [Mart] J.F. Macbr	1
58	Prosopis velutina	1
59	Punica Granatun L.	1
60	Rhamnus saxatilis aiaca	1
61	Rhamnus saxatilis jaca	2
62	Rhus virens	2
63	Robina pseudoacacia	3
64	Roseodendron donell smithi [Rose]	1
65	Salvadora Persica	10
66	Sena occidentalis	2
67	Sesbama Punicea Cav. Benth	1
68	Ulmus parusfolia sac	4
69	Vachellia farnesiana l.	73
70	Vachellia nilotica	2
71	Viburnum adoratissimum	3
72	Vitex agnus cactus	1
73	Ficus rubiginosa	1
74	Psidium cattleyanum Sabine	2
75	Morus alba	1
76	Prunus serotina	1
	Total	590

The 559 species were subsequently grouped by family in order to manage more compact data on the map, quantifying a total of 34 families, catalogued by colour [Table 2]. The family with the most abundant species is Fabaceae.

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Box 7

Table 2

Botanical families found at the John Paul II headquarters

	Family	Quantity
1	Unknown	31
2	Anarcadiaceae	60
3	Apocynaceae	39
4	Arecaceae	3
5	Asteraceae	1
6	Bignoniaceae	20
7	Casuarinaceae	8
8	Euphorbiaceae	3
9	Fabaceae	103
10	Lauraceae	1
11	Malvaceae	21
12	Moraceae	10
13	Nyctaginaceae	57
14	Olaceae	77
15	Rosaceae	2
16	Rutaceae	4
17	Sapindaceae	6
18	Solanaceae	11
19	Ulmaceae	4
20	Burseraceae	2
21	Caricaceae	1
22	Vitaceae	1
23	Ficus	4
24	Araliaceae	1
25	Myrtaceae	7
26	Sapotaceae	10
27	Meliaceae	3
28	Leguminosae	8
29	Lythraceae	1
30	Rhamnaceae	1
31	Eukaryota	2
32	Salvadoraceae	10
33	Vachellia	73
34	Adoxaceae	3
35	Lamiaceae	1
35	Nymphaeaceae	1
	Total	590

Using orthoimages, a map was created in AutoCAD showing the location and distribution of trees on the grounds of the Juan Pablo II headquarters by family [Figure 6].

Box 8

Figure 6

Map of the trees at the headquarters by botanical families

Prepared by the author

In terms of tree characteristics, the minimum diameter is 4 cm and the maximum is 270 cm. The condition of the trees was recorded, finding that 22.54% of the trees are in excellent condition, 34.92% are in good condition, 4.75% are fair, 10.34% are poor, 19.32% are critical, and 8.14% are dead [Table 3].

Box 9

Table 3

Tree conditioner

Condition	Quantity
Excellent	133
Good	206
Fair	28
Poor	61
Critical	114
Dead	48
Total	590

In addition, the exposure to sunlight of each of the specimens was observed, finding that 85.76% are completely exposed to sunlight, 14.24% are partially exposed, and none are in the shade, as shown in Table 4.

Box 10

Table 4

Sun exposure

Exposure	Quantity
Full	506
Partial	84
Shade	0
Total	590

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Conclusions

The findings show that vegetation changes dramatically depending on the season, low water period [March-May] and rainy season [June-August], which is consistent with the type of vegetation that exists in the area, namely low deciduous forest and scrubland, as can be seen from the orthoimages. Celaya is a municipality with little natural vegetation, which speaks to its degree of anthropisation, but the remnants of vegetation, such as those at the Juan Pablo II headquarters, are well preserved and consist of continuous massifs with little fragmentation of the landscape. The tree species found in the study area are native to the area, indicating that they are adapted to the soil and have the necessary nutritional requirements, so it can be deduced that they do not suffer from stress, allowing them to perform their carbon sequestration and water capture functions.

Of the 559 trees counted, 75 species were found, with Vachellia farnesiana being the most abundant, followed by Bougainvillea and, in third place, Schinus molle L. As for families, 3.4 were characterised, with Fabaceae occupying first place, followed by Olaceae and then Vachellia. The location of the trees within the headquarters suggests that they can help cool the air by between 2 and 8 degrees Celsius. The mature trees found regulate water flow and play a key role in preventing flooding and reducing the risk of natural disasters. This ecosystem benefit is relevant given that the Celaya region suffers from severe flooding due to its mostly flat topography.

The University of Guanajuato's commitment to reforestation is evident, as it was possible to visualise the planting of young trees, and 57.46% of existing trees are in excellent or good condition. It is worth mentioning that none of the trees counted are in the shade, which allows them to carry out the process of photosynthesis properly, in addition to regulating the ambient temperature and providing ecosystem services.

The growth of a city is inevitable in most cases because it is essential to meet the demands of urban environments, including education, as in the case of the Juan Pablo II Campus; however, these vocations should not conflict with each other.

This inventory may be useful for the campus, as knowing the location, distribution, and characteristics of the trees with the help of spatial analysis allows for assessments and decision-making in terms of maintenance, reforestation, future growth, and sustainable land use management for the space in question.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Contribution of the authors

Palacios-Hernández, Otoniel: Contributed to the management of the field brigade to obtain orthoimages, contour lines, and a 2D plan with the spatial location of the trees.

Moreno-Martínez, Viridiana: Contributed to the identification of trees with respect to species, family, condition, diameter, and sun exposure.

Availability of data and materials

The data are available for use for research purposes.

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Article

Influence of stress state on volumetric behaviour of soils

Influencia del estado de esfuerzos en el comportamiento volumétrico de los suelos

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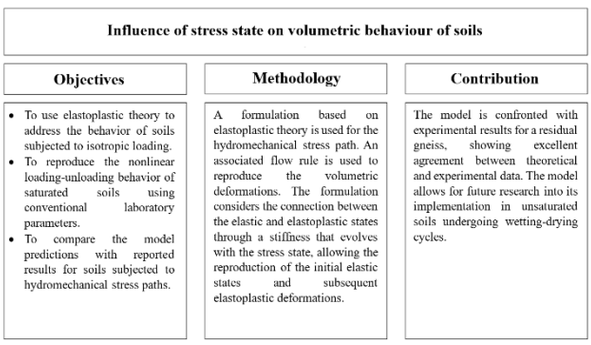
Abstract

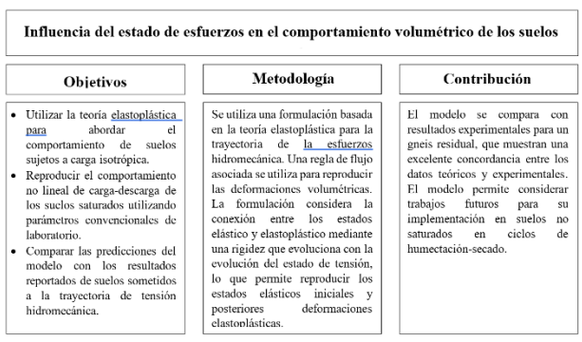
Soils are versatile yet difficult to predict because their strength and structure cannot be controlled unlike concrete or steel: their grains move freely, constantly modifying the microstructure and closing voids [which increase strength]. This behaviour is governed by hydro-mechanical coupling where compression reduces pore size, lowers hydraulic conductivity, and enhances shear strength. This research paper reproduces the nonlinear response of soils which evolve with each strain increment, strongly influenced by preconsolidation stress. Below this threshold, soils behave elastically and recover upon unloading; beyond it, particle displacement, friction, and energy dissipation occur. The transition from elastic to plastic behaviour is gradual, requiring constitutive models that capture both regimes. The model results are confronted with experimental data exhibiting good theoretical-experimental agreement.



Isotropic consolidation, Saturated soil, Mechanical behaviour

Resumen

Los suelos son versátiles, pero difíciles de predecir ya que su resistencia y estructura no se pueden controlar a diferencia del hormigón o el acero: sus granos se mueven libremente, modificando constantemente la microestructura y cerrando huecos [lo que aumenta la resistencia]. Este comportamiento se rige por el acoplamiento hidromecánico, donde la compresión reduce el tamaño de los poros, disminuye la conductividad hidráulica y mejora la resistencia al corte. Este trabajo de investigación reproduce la respuesta no lineal de los suelos que evoluciona con cada incremento de la deformación fuertemente influenciada por la tensión de preconsolidación. Por debajo de este umbral, los suelos se comportan elásticamente y se recuperan al descargarse; por encima de él, se produce desplazamiento de partículas, fricción y disipación de energía. La transición del comportamiento elástico al plástico es gradual, lo que requiere modelos constitutivos que capturen ambos regímenes. Los resultados del modelo se comparan con datos experimentales que muestran una buena concordancia teórico-experimental.



Consolidación isotrópica, Suelo saturado, Comportamiento mecánico

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

Soils are the most versatile building materials, but also the most difficult to predict. This is because, in their abundance, they exhibit a range of behaviours that are not easily foreseen [Rotta Loria et al., 2023]. The fundamental difference between soils and other building materials like concrete or steel is that their strength and internal structure cannot be controlled. In concrete, for example, we can modify its compressive strength by adjusting the proportions of its components. This procedure is not feasible for soils because it would be prohibitively expensive.

An additional consequence of the internal structure of soils is that their individual grains are in free movement. Therefore, when subjected to external stress, the particles must deform to balance and withstand this stress. This deformation, for example, is not possible in concrete because its individual grains are tightly bound together by the cement between them.

These differences lead to a constant modification of the soil's microstructure, a phenomenon that does not occur in other materials. This, in turn, results in the constant strength of these materials because their individual components close the empty spaces between them, thus increasing their strength due to the reduced space for volumetric deformations.

These ideas are framed within a concept that can be expressed as hydro-mechanical coupling of soils [Arroyo & Rojas, 2019; Della Vecchia & Romero, 2012] which means that the hydraulic properties of soils affect mechanical ones and vice versa. For instance, if a soil is compressed, the volume reduction affects the size of the pores that water can pass through, reducing its hydraulic conductivity. Moreover, this also has the consequence of increasing the shear strength because, due to the pore closure, individual particles are closer to each other having an overall increased strength [Arroyo et al., 2015; Zhang et al., 2020; Zolfaghari & Piri, 2017].

When the soil material is being stressed, the observed behaviour is nonlinear, which means that it cannot be predicted by simple linear rules. This is because of the aforementioned behaviour of particle moving thus producing a different material every strain suffered.

Shear resistance is not on the scope of this paper, however, it is very common to observe triaxial compression tests that receive large stresses producing a nonlinear behaviour up to failure [Weber et al., 2022; Wei et al., 2022].

When it comes to volumetric deformations, the friction between particles contribute to the strength that the bulk of the soil exhibit to external stresses. All soil materials appertain a certain mechanical feature called preconsolidation stress, which is actually the external stress that the internal consequences can sustain [Nuth & Laloui, 2008; Rojas, 2022]. When external stresses are smaller than the preconsolidation stress, the strain behaviour, when plotted in a cartesian axis, it recalls very much to a proportional relationship such as elastic materials [Amorosi et al., 2020; Della Vecchia & Romero, 2012]. When it reaches certain stress level, strains develop much faster and an elastic linear behaviour is no longer exhibited.

A specific feature of these ideas is that, if a soil material is unloaded before it reaches its preconsolidation stress, it recovers almost all its initial configuration. This is because, the particles have sustained themselves all the stress without needing any displacement of them relative to each other.

However, if preconsolidation stress is surpassed, the particles themselves cannot sustain the external stress and displacement of them is needed. Then, friction happens, and dissipation of energy is exhibited, sometimes even in the form of heat [Arroyo et al., 2015; Laloui, 2006].

This paper deals with this constitutive framework, dealing with the prediction of this initial linear and further nonlinear behaviour. However, it is very clear that this transition is not a sharp one. It is instead gradual and because of this, a connection with “later” plastic strains when elastic ones are exhibited for stresses smaller than the preconsolidation stress, is needed.

The constitutive model

The proposed constitutive model is elastoplastic in nature. The void ratios, e, will be used to express the volumetric changes.

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In an elastoplastic model, volumetric deformations can be partitioned into elastic and plastic:

$$e = e^e + e^p \quad [1]$$

Elastoplastic theory allows us to relate volumetric plastic deformations $d\varepsilon_v^p = de/(1+e)$ to the yield surface f, where f generally takes the form of an ellipse [Dai et al., 2024; Mu et al., 2023; Muir Wood, 1990]. However, the present analysis is specifically restricted to deformations undergone in the isotropic domain and, therefore, is of exclusive interest what occurs under the application of isotropic stresses p.

In the case of triaxial compression, the value of the isotropic stress coincides with that of the confining stress applied to a triaxial compression chamber.In this sense, under the elastoplastic theory, it is possible to identify a proportionality between the volumetric deformations and the state of stress on the yield surface ∂f/∂p [Muir Wood, 1990], through a parameter L:

$$d\varepsilon_v^p = L\frac{\partial f}{\partial p} \quad [2]$$

Replacing Equation [2] in Equation [1], the change in void ratios can be obtained:

$$de_v^p = d\varepsilon_v^p(1+e) = L\frac{\partial f}{\partial p}(1+e) \quad [3]$$

If the consistency condition for plastic deformations is considered:

$$df = \frac{\partial f}{\partial p}dp + \frac{\partial f}{\partial q}dq + \frac{\partial f}{\partial p_0}dp_0 = 0 \quad [4]$$

Where p_0 is the size of the yield function f, and p and q are the isotropic and deviator stress, respectively.

It is important to note that, classical elastopilastic models such as the Cam Clay [Roscoe & Burland, 1968], use also a plastic potential function g in order to define the magnitude of the plastic deformations related to the yield function f. In general, the plastic potential function is very much the same as the yield function in terms of its shape.

However, the aforementioned is expressed in terms of the plastic increments of strains [produced by deviator and isotropic strains]. However, if it is considered that the material will behave isotropically, it is enough to provide an associated mechanism of behavior between the yield function and the plastic potential function.

This is because they actually resemble each other when plotted in a cartesian space. However, this is not the case for anisotropic materials such as sedimentary deposits of natural soil materials nor the majority of the rock materials or highly consolidated soils.

However, this research paper works with the associated flow rule because the studied materials do work under that scheme. Because of this, the mathematical formulation is less complex and the implementation of the model equations is easier in any computational platform [Arroyo et al., 2024].

Hence, parameter L can be defined as:

$$L = \frac{\frac{\partial f}{\partial p}dp + \frac{\partial f}{\partial q}dq}{K} \quad [5]$$

Where K establishes the stiffness of the material. Of course, K varies as the stress state progresses [Dai et al., 2024], and this parameter allows for a connection between the deformed and undeformed states of the soil.

Evolution of *K* with stress state

Figure 1 shows the initial stress state $\sigma = [p,q] = [p,0]$ within the yielding surface f. In this research paper, Equation [6] is proposed for the model, which establishes a connection between future and present strain states through d_1 and d_2. It is in fact, a very common type of proposal [Jung & Yune, 2011; Russell & Khalili, 2004; Seidalinov & Taiebat, 2014; Wang et al., 2022]. Here, the idea is to produce a relationship for the plastic states and the elastic states, combining it to act in specific stress states.

Note that d_1 is the distance from the origin of coordinates, and d_2 is the distance from the same origin to a projected point at p_0. As the stress progresses and σ increases, the value of d_1 approaches d_2. Once $d_1 = d_2$, the stiffness value takes the usual value of the Modified Cam Clay Model [MCCM].

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Box 1

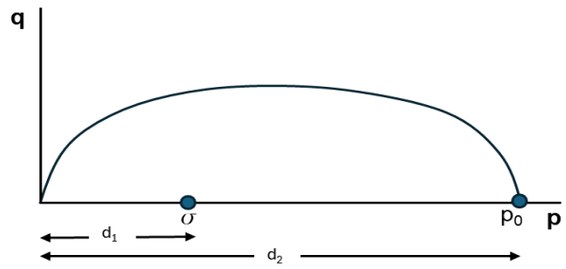

Figure 1

Schematic of yield function f for the model
Source: Own elaboration

$$K = -\left(\frac{\partial f}{\partial p_0}\right)^2 \frac{\partial p_0}{\partial \varepsilon_v^p}\left[1 + C\left(1 - \left(\frac{d_1}{d_2}\right)\right)\right] \quad [6]$$

Function $\frac{\partial p_0}{\partial \varepsilon_v^p}$ can be obtained from the proposal of Rojas et al. [2015], where:

$$\frac{dp_0}{d\varepsilon_v^p} = \frac{1+e}{e} p_0 \frac{1}{\lambda - \kappa} \quad [7]$$

A paramount feature of Equation [6], is that it restricts the volume deformation, inhibiting indefinite deformations thus providing a more real mechanical framework.

In Equation [7], λ and κ are soil compressibility parameters that can be easily obtained from a consolidation test in an oedometer or an isotropic consolidation test. Function $\frac{\partial f}{\partial p_0}$ may be obtained by elaborating a partial derivative for p_0. For this, the classic shape for f as that of the MCCM will be adopted.

Finally, it is needed to calibrate parameter C in Equation [5]. In Figure 2, the influence of C is depicted for a hypothetical soil material with an initial void ratio of 1.0.

Box 2

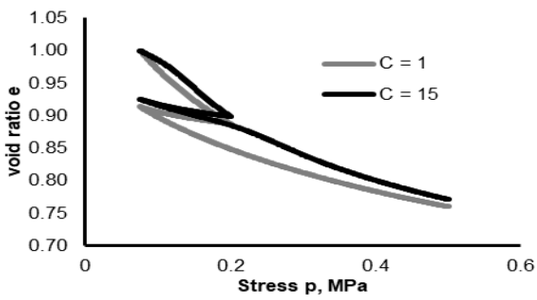

Figure 2

Influence of parameter C on soil stiffness
Source: Own elaboration

The material is stressed starting from 75 kPa to 200 kPa, then unloaded to the initial stress [75 kPa] and then re-loaded to 500 kPa. Both simulations show remarkable differences. For instance, it can be seen that the material that reaches the larger volume deformations is the one with $C = 1$, which is consistent since a smaller value produces a larger L, and thus larger volume strains.

It can be seen from Figure 2, that the larger differences are seen between 200 and 400 kPa, however, the model provides almost the same final void ratio at the end of the stresses path. This is in accordance with reported experimental data [Arroyo & Rojas, 2019], where it can be seen that the soil material slows down its deformation as it reaches larger stresses.

This is because, pore space will not indefinitely close unless individual particles break.

Theoretical-experimental result comparisons

The experimental results of a saturated soil subjected to isotropic compression will be compared with the predictions of the volumetric strain model.

This is a low-plasticity soil with a specific gravity of solids of 2.65. Its initial void ratio is 0.486 and its compressibility parameters are λ=0.167 and κ=0.03. The experimental programme is reported elsewhere [Gens, 1982].

The soil samples are fabricated departing from a slurry soil. It is placed within a triaxial cell to compress it isotropically. Afterwards, the materials excess pore water pressure is expelled by consolidating the material under isotropic stress. The goal for this previous experimental programme was to produce an isotropic material that would allow to discard the anisotropic conditions and furtherly evaluate the mechanical behaviour of them both [anisotropic and isotropic].

This research paper's goal is to analyse the isotropic behaviour material. Further research is oriented towards the mechanical behaviour of anisotropic granular material under unsaturated and saturated conditions.

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Box 3

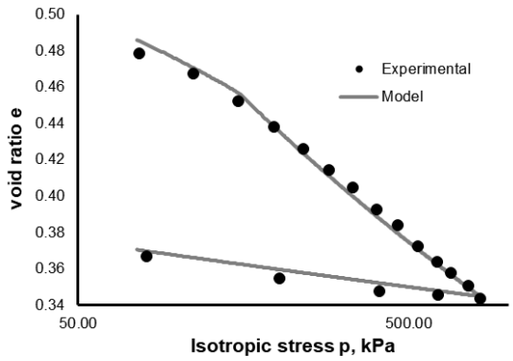

Figure 3

Numerical-experimental result comparisons for the volumetric behavior of a saturated soil subjected to isotropic compression.

Source: Own elaboration

As can be noted from Figure 3, the initial void ratio is 0.48 and the preconsolidation stress is 200 kPa. The simulations start stressing the material from the starting point of 75 kPa and goes further than the preconsolidation stress up to 823 kPa ad then unloaded up to 75 kPa again.

Because of the features of the model used, the initial elastic zone [from 75 to 200 kPa] shows different slope than that of the unloading ranghe [827 to 75 kPa], even though the same elastic slope parameter is being used [$\kappa = 0.03$]. This are the most distinctive features when compared to classic elastoplastic models.

Here, the reason for this behavior, is that the elastic inner zone, within the yielding surface f, is connected to the plastic zone through the distances d_1 and d_2, providing an elastoplastic behavior even at the stress range that would be identified as purely elastic [Chen et al., 2019].

Conclusions

A constitutive elastoplastic model has been proposed. The model is formulated under the elastoplastic theory providing a yielding function that works that uses a plastic flow rule, the consistency condition

The model distinctive feature is the formulation of the stiffness parameter K, allowing a connection between elasti and plastic zones. The connection is provided by a nonlinear relationship that is evaluated determining the distance between a projection center at the origin or the stress space, and the yielding surface f.

Because of this, a soft transition between elastic and plastic states is observed for the numerical purposes. A drawback of the present model is the need for calibration of parameter C. This is because this parameter can be variated between a narrow range but still has strong influence on the predicted stresses.

The model is confronted with experimental results reported elsewhere for a residual gneiss showing excellent agreement between the theoretical and the experimental data.

Future work is oriented towards the implementation of the present model for unsaturated soils allowing the prediction and inclusion of wetting-drying cycles on the overall strength and volume behavior of the soil materials.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Arroyo, Hiram: Contributed to data analysis and interpretation, manuscript writing and revision.

Palos-Barba, Viviana: Contributed to the project idea, research method, technique and manuscript revision.

Chávez-Cárdenas, Xavier: Contributed to data analysis.

Availability of data and materials

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Abbreviations

MCCM	Modified Cam Clay Model

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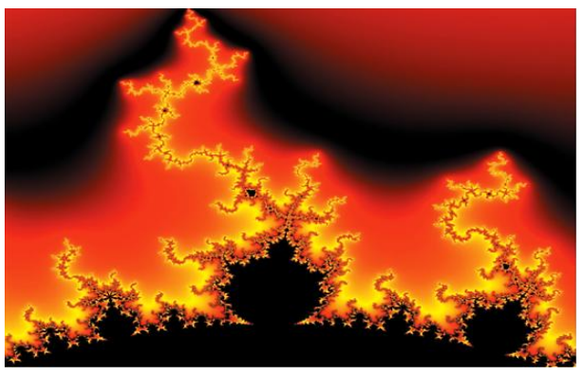

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ANN	Artificial Neural Network

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