

**Intelligent Progressive Web Application for sustainable tourism in Mexico**IDALIA MALDONADO CATILLO<sup>1</sup>, JOSUE MONTALBAN ROJAS<sup>2</sup>, GERARDO URIEL ORTIZ RAMIREZ<sup>3</sup><sup>1</sup> Computer Systems Engineering Department, Escuela Superior de Cómputo (ESCOM), Instituto Politécnico Nacional, Mexico City, Mexico.<sup>2</sup> Engineering Department, Escuela Superior de Cómputo (ESCOM), Instituto Politécnico Nacional, Mexico City, Mexico.<sup>3</sup> Engineering Department, Escuela Superior de Cómputo (ESCOM), Instituto Politécnico Nacional, Mexico City, Mexico.Email: <sup>1</sup>imaldonadoc@ipn.mx, <sup>2</sup>jmontalbanr2000@alumno.ipn.mx, <sup>3</sup>gortizr2001@alumno.ipn.mxOrchid Id number: <sup>1</sup>0000-0002-2594-1945, <sup>2</sup>0009-0009-3267-7546, <sup>3</sup>0009-0006-6211-1293

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**ABSTRACT:** This paper presents the design and implementation of an intelligent Progressive Web Application (PWA) for sustainable tourism in Mexico. The proposed system, which utilizes an Ant Colony Optimization (ACO) algorithm to generate the best solution for itineraries, provides personalized and eco-conscious travel recommendations for four key Mexican states, based on the country's Sustainable Development Indicators. The PWA analyzes visitor preferences to generate optimized travel routes and suggest destinations, focusing on sites of interest. A core component of this research is the integration of a sustainability heuristic within the ACO model, which prioritizes accommodation with certified sustainability credentials. The PWA novelty lies in its dual focus on user personalization and environmental responsibility. It offers users a choice between a standard itinerary and a more sustainable one, providing transparency by calculating and displaying the carbon footprint generated by using the application itself. The PWA is designed for seamless cross-platform access, offering an efficient and user-friendly platform. Our results demonstrate that the system effectively delivers tailored recommendations while actively promoting responsible travel practices, making it a valuable tool for advancing sustainable tourism in Mexico.

**KEYWORDS:** Progressive Web Application, Sustainable Tourism, Ant Colony Optimization, Itinerary Optimization, Carbon Accounting, Environmental Impact Assessment, Mexico.

**1) Introduction:**

Tourism is one of the fundamental pillars of the Mexican economy, contributing significantly to GDP and generating jobs for millions of people [1]. However, the rapid growth of tourism has brought negative environmental externalities, with the sector responsible for approximately 8% of global greenhouse gas emissions due to transportation, accommodation energy consumption, and fossil fuel use [2]. Mexico faces a particularly significant impact as one of the world's most visited destinations [3].

Current digital tourism platforms are limited to offering recommendations based on geographic location or commercial interests, often neglecting users' personal preferences and the environmental impact of tourist activities [4]. This represents a missed opportunity to promote sustainable tourism, as travellers' decisions could be guided toward environmentally friendly practices with appropriate tools.

Tourist itinerary optimization is a complex combinatorial problem requiring algorithms capable of balancing multiple conflicting objectives: travel efficiency, destination attractiveness, and environmental impact. Ant Colony Optimization (ACO) is particularly suitable for this challenge due to its proven effectiveness in routing problems and its ability to integrate diverse sustainability criteria through probabilistic decision-making [7,8].

In response to this problem, we propose developing a Progressive Web Application that uses an Ant Colony Optimization (ACO) algorithm as an artificial intelligence model to offer personalized recommendations to tourists. The system considers both personal preferences and environmental impact of travel choices. This tool seeks to reduce tourism's carbon footprint by suggesting itineraries that prioritize accommodation with certified sustainability credentials and destinations that promote sustainable settlements. This approach aims to contribute to more responsible tourism in Mexico, aligning with the National Sustainable Tourism Strategy objectives [5].

**2) Methods and Methodology:**

Our proposal consists of a Progressive Web Application (PWA) called "Huellas por México" that integrates artificial intelligence techniques to recommend tourist destinations in a personalized and sustainable way.

The application generates itineraries tailored to user preferences and selects four tourist destinations based on ecological criteria such as energy consumption, carbon emissions, environmental certifications, and other sustainability indicators. Unlike conventional platforms, which tend to prioritize the most popular destinations, this proposal favors options with a lower environmental impact. It also allows users to view the estimated carbon footprint of their trip and offers practical recommendations for reducing it, promoting sustainable tourism.

**2.1 Geographical Delimitation**

The Instituto Nacional de Estadística y Geografía (INEGI), Mexico's national statistics agency, collects information on the entries of foreigners and residents in each state. Data from the 32 Mexican states for the years 2019, 2022, 2023, and 2024 were analyzed to calculate an average and determine which states are the most visited in the country. The years 2020 and 2021 were excluded from the analysis due to travel restrictions and anomalous tourism patterns resulting from the COVID-19 pandemic, which would have skewed the representative baseline of typical tourist behavior.

Based on an analysis of the average number of annual visitors, the four entities with the highest visitor numbers were identified.

**Table 1:** Average Annual Tourist Arrivals by State

Entity	Annual average
Quintana Roo	16,518,082
Ciudad de México	8,378,625
Jalisco	4,481,530
Nuevo León	866,094

The states of Quintana Roo, Mexico City, Jalisco, and Nuevo León were selected for this project because, according to available data, they represent the destinations with the highest average number of annual visitors in the country. These states stand out for their tourism infrastructure, national and international connectivity, and the diversity of attractions they offer, making them key points for analyzing tourism behavior in Mexico.

Within the PWA, we recommend lodging options that hold internationally recognized sustainability certifications such as EarthCheck, Rainforest Alliance, Biosphere, LEED, Green Key, and Mexico's Distintivo S with the purpose of ensuring responsible practices in the development and operation of these establishments. These certifications not only validate the hotel sector's environmental commitment, but also promote efficiency in the use of resources, reduction of polluting emissions, protection of biodiversity, local development, and responsible management of natural resources. The adoption of these standards will allow hotels to align themselves with the Sustainable Development Goals and respond to the growing demand for more conscious, responsible, and competitive tourism. Furthermore, the selection of Quintana Roo, Mexico City, Jalisco, and Nuevo León as focal states for this project is not only due to their high volume of annual visitors, but also because these regions already have a significant number of certified sustainable hotels, making them ideal for further promoting and expanding sustainable tourism initiatives

**2.2. Sustainability Heuristic Integration**

Following the geographical delimitation, a comprehensive sustainability assessment was conducted at the municipal level. The sustainability index serves as a composite metric that quantifies the environmental impact of tourist destinations, providing a standardized measure for integration into the ACO algorithm's heuristic function.

Data for the sustainability assessment were obtained from multiple official sources: INEGI's Municipal Statistical Yearbooks (2023-2024) for energy consumption, water usage, and waste generation; the National Institute of Ecology and Climate Change (INECC) for carbon emissions data; and the Mexican Tourism Board (SECTUR) for visitor statistics and accommodation capacity. Municipal-level data were aggregated for 156 municipalities across the four selected states, representing all major tourist destinations within these regions.

The index incorporates nine key sustainability indicators: carbon emissions from transport (ton CO<sub>2</sub>), energy consumption (kWh), waste management emissions (ton CO<sub>2</sub>), accommodation capacity, potable water consumption (m<sup>3</sup>), estimated visitors, tourist density (visitors/km<sup>2</sup>), solid waste generation (ton), and total carbon footprint. Due to the heterogeneous nature of these variables, Z-score standardization transforms each indicator [6]:

$$z = \frac{x - \mu}{\sigma}$$

where  $x$  represents the original value,  $\mu$  the mean across all settlements, and  $\sigma$  the standard deviation.

A Random Forest algorithm was selected to process these indicators and generate the final sustainability index due to its ability to handle non-linear relationships between variables, its robustness to outliers in environmental data, and its interpretability through feature importance analysis [7]. The model was trained on 70% of the municipal data (n=109) and validated on the remaining 30% (n=47), using 100 decision trees with a maximum depth of 10. The trained model achieved a cross-validation accuracy of 0.87 (±0.03), with mean absolute error of 0.08 on the test set. The final sustainability index is scaled between 0 and 1, where higher values indicate greater sustainability. This municipal-level assessment enables the ACO algorithm to incorporate sustainability variations into itinerary generation.

### 2.3 Ant Colony Optimization Algorithm Implementation

The Ant Colony Optimization (ACO) algorithm is a bio-inspired metaheuristic that simulates ant foraging behavior to solve combinatorial optimization problems [8]. ACO exploits the indirect communication mechanism of real ants through pheromone trails, enabling them to find short paths between their nest and food sources [8,9]. This characteristic is transferred into algorithms that can be applied to a wide range of discrete and continuous optimization problems.

In nature, ants deposit pheromones while searching for food, with shorter paths receiving more pheromones as they are traversed more frequently, creating a positive feedback mechanism that leads to optimal route discovery [8,9]. The longer a path takes to traverse, the more time pheromones must evaporate, making shorter paths naturally more attractive to subsequent ants.

In this work, ACO is applied to generate sustainable tourism itineraries by evaluating multiple criteria simultaneously. Each artificial ant constructs candidate solutions using a probabilistic decision rule that combines pheromone intensity ( $\tau$ ) and heuristic information ( $\eta$ ). The probability that ant  $k$  moves from location  $i$  to location  $j$  is given by [8]:

$$p_{ij}^k = \frac{[\tau_{ij}]^\alpha [n_{ij}]^\beta}{\sum_{N_i^k} ([\tau_{ij}]^\alpha [n_{ij}]^\beta)}$$

where  $\alpha$  and  $\beta$  are parameters that control the relative influence of pheromone trails and heuristic visibility, respectively, and  $N_i^k$  represents the feasible neighborhood of ant  $k$  at location  $i$ .

The heuristic visibility represents a comprehensive attractiveness measure incorporating six variables: municipal sustainability index (30% weight), user rating (15% weight), proximity factor (15% weight), temporal availability (15% weight), experience diversity (15% weight), and time feasibility (10% weight). This multi-criteria heuristic is calculated as:

$$n_{ij} = \frac{1}{d_{ij}}$$

where each component is normalized to ensure balanced contribution to the decision-making process.

The algorithm updates pheromone levels through evaporation and reinforcement processes [8,9]. After all ants complete their tours, pheromones evaporate at rate  $p$  and are reinforced based on solution quality:

$$\Delta\tau_{ij}^k = \frac{Q}{L_k} \quad \tau_{ij} = (1 - p)\tau_{ij} + \sum \Delta\tau_{ij}^k$$

where  $Q$  is a constant and  $L_k$  is the length of the tour constructed by ant  $k$ . This evaporation mechanism prevents premature convergence to locally optimal solutions and maintains exploration of the solution space [9]. The positive feedback mechanism allows convergence toward sustainable solutions that balance distance, time, and environmental considerations while prioritizing certified sustainable accommodations.

### 2.4 System Architecture

The system implements a microservices architecture deployed on Microsoft Azure, comprising two independent services coordinated through an API Gateway. The Tourism Management Service, developed in Java Spring Boot containerized in Docker, provides core functionality including user authentication, profile management, and external API integration. This service maintains the master repository for points of interest and accommodation data.

The Itinerary Optimization Service, implemented in .NET C# as Azure Functions, executes the Ant Colony Optimization algorithm. This service performs three primary operations: municipal sustainability heuristic computation based on normalized environmental indicators, pheromone matrix initialization and management, and probabilistic route construction through artificial ant simulation. The service retrieves tourism data via RESTful APIs from the Tourism Management Service and persists generated itineraries independently.

The client interface consists of a Vue.js Progressive Web Application that communicates with both backend services through the API Gateway. Each microservice operates with dedicated PostgreSQL databases, providing data isolation, fault tolerance, and horizontal scalability.

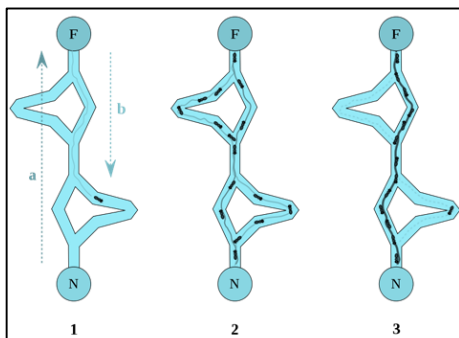


Figure 1(a) Ant's foraging behavior

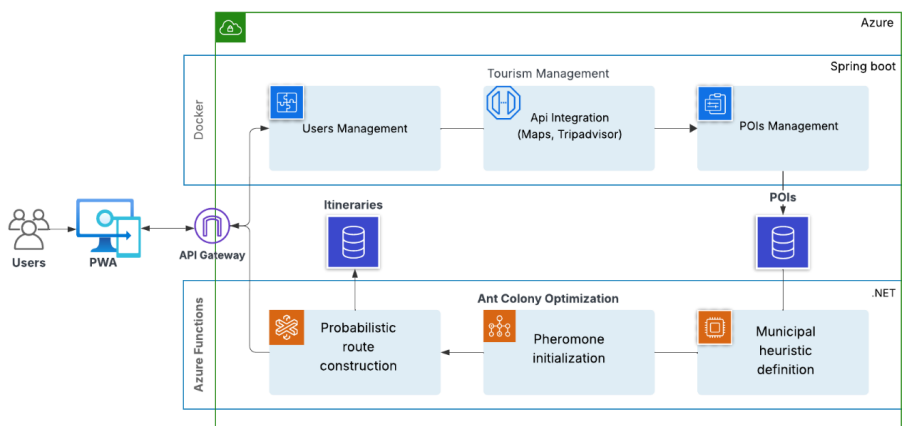


Figure 2(a) Architecture system diagram

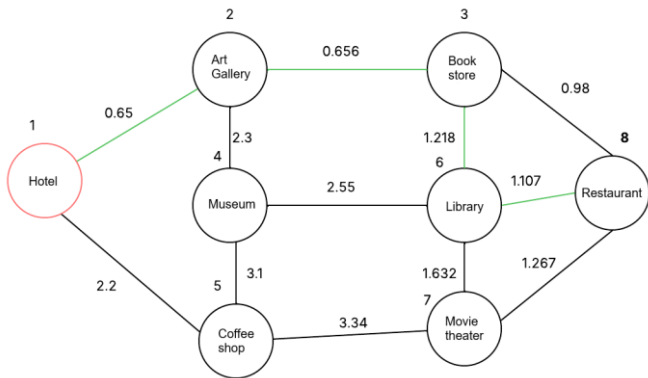
2.5 Carbon Footprint Calculation: Computing systems represent approximately 0.5% of global energy consumption, yet measuring individual software carbon impact remains challenging. The system implements real-time carbon footprint tracking based on hardware resource monitoring following the CodeCarbon methodology [10]. Following the CodeCarbon approach, carbon emissions are calculated as the product of energy consumption and carbon intensity [9]:

$$CO_{2eq} = C * E$$

where C represents the Carbon Intensity of electricity consumed (gCO<sub>2</sub>/kWh) and E represents the Energy Consumed by computational infrastructure (kWh). For this implementation, the system tracks four primary emission sources during application execution: CPU processing time, memory (RAM) usage, database query operations, and HTTP request handling. The total carbon footprint is estimated to be using empirically derived coefficients based on typical hardware consumption patterns. The Ant Colony Optimization algorithm represents the most computationally intensive operation, requiring substantial CPU cycles for probability calculations, memory allocation for pheromone matrices, and multiple database queries during itinerary optimization. The system automatically captures these execution metrics using aspect-oriented programming, providing users with real-time feedback about their digital environmental impact.

**3) Results:**

The ACO algorithm implementation utilized 30 artificial ants across 50 iterations to explore solution spaces centered on user-selected sustainable hotels from four target Mexican states. Algorithm parameters ( $\alpha=1$ ,  $\beta=2$ , evaporation rate  $\rho=0.5$ ) were determined through preliminary sensitivity analysis, enabling effective balance between pheromone trail exploitation and heuristic exploration.



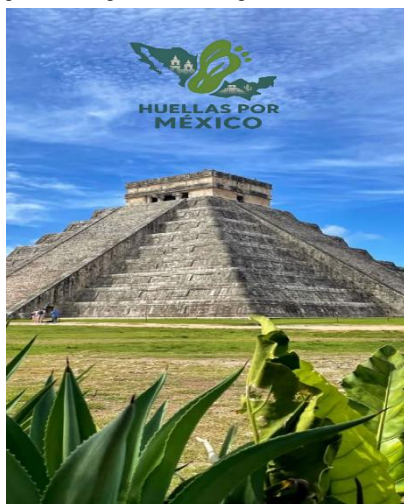
The ACO algorithm implementation utilized 30 artificial ants across 50 iterations to explore solution spaces centered on user-selected sustainable hotels from four target Mexican states. Algorithm parameters ( $\alpha=1$ ,  $\beta=2$ , evaporation rate= $0.5$ ) enabled effective balance between pheromone trail exploitation and heuristic exploration of destinations within proximity to chosen accommodations. Testing with real tourism data from Quintana Roo, Mexico City, Jalisco, and Nuevo León demonstrated the system's capability to generate practical multi-day itineraries incorporating diverse attraction types while maintaining optimal travel distances. The municipal-level sustainability assessment successfully integrated nine environmental indicators into the ACO heuristic function, with route quality evaluation using a composite scoring function (sustainability 40%, user ratings 20%, distance efficiency 20%, destination diversity 20%) showing convergence toward high-quality solutions within 30-40 iterations.

**Figure 3(a) ACO algorithm results**

**Table 2:** Comprehensive ACO algorithm results

Parameter	Optimal Route Segments				Average
	Hotel – Art Gallery	Art Gallery – Book store	Book store - Library	Library - Restaurant	
<b>Route Characteristics</b>					
Distance (km)	0.650	0.656	1.218	1.107	<b>3.631</b>
Estimated time (hrs)	0.8	0.9	1.5	1.3	<b>4.5</b>
Sustainability index	0.85	0.82	0.79	0.84	<b>0.82</b>
Ratings	4.7/5.0	4.5/5.0	4.3/5.0	4.6/5.0	<b>4.5/5.0</b>
<b>ACO Algorithm Parameters</b>					
Visibility $\eta(e)$	1.538	1.524	0.821	0.903	1.197
Initial pheromone $\tau_0$	0.100	0.100	0.100	0.100	0.100
Final pheromone $\tau_f$	<b>0.3744</b>	<b>0.3744</b>	<b>0.3744</b>	<b>0.3744</b>	<b>0.3744</b>
Selection probability %	77.36	77.99	44.54	59.49	64.85
Pheromone deposit $\Delta\tau$	0.2754	0.2754	0.2754	0.2754	0.2754

Final itineraries achieve average sustainability scores of 0.82 while maintaining practical travel constraints and user preference satisfaction for destination types around selected sustainable accommodations. The optimal route (Hotel → Art Gallery → Bookstore → Library → Restaurant) demonstrates effective balancing of multiple sustainability criteria through the ACO algorithm's probabilistic selection mechanism. Convergence occurred within 35 iterations with consistent pheromone reinforcement on high-quality path segments, validating the algorithm's ability to identify globally optimal solutions for sustainable tourism itinerary generation. The integration of certified sustainable accommodations and municipal-level environmental indicators ensures that recommended itineraries actively promote responsible travel practices while delivering personalized tourism experiences.



*Figure 4(a). Home screen of the "Huellas por México" PWA, showing the app logo and one of the seven wonders of the world, Chichén Itzá. This initial interface welcomes users before they begin their personalized, AI generated sustainable travel planning experience.*



Figure 5(a) Itinerary description screen, description screen of the generated travel itinerary, showing the title of the tour, the city to visit, the number of places included, the dates of the trip and an environmental impact indicator. In addition, the selected lodging is presented with its respective sustainability certification, along with a list of tourist attractions including name, location, rating and shortcuts to see the description or go to the place.

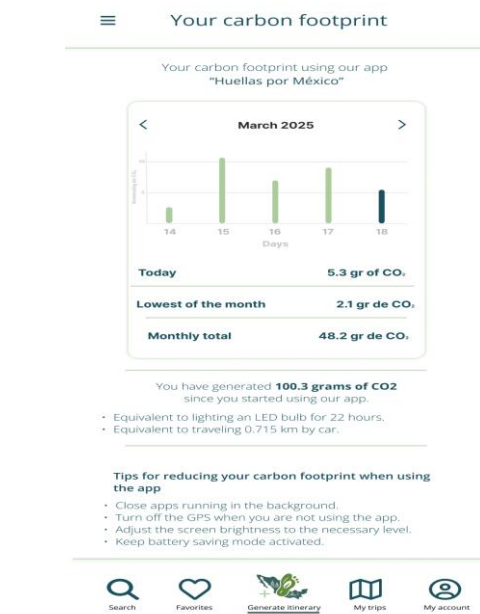


Figure 6(a) Screen to show the carbon footprint. Tracking screen showing the history of CO2 emissions generated by the use of the “Footprints for Mexico” application. The interface presents daily trends for the current month, the current day's emissions, the lowest CO2 value for the month, the monthly cumulative total, and practical tips for reducing environmental impact during trip planning.

**4) Discussion**

The ACO algorithm achieved convergence within 30-40 iterations with a pheromone increase on optimal paths, demonstrating efficient solution identification compared to reported convergence rates in similar applications [8,9]. The multi-criteria heuristic function successfully balanced competing objectives, with sustainability weighting (40%) producing routes that reduced carbon emissions while maintaining high user satisfaction (4.5/5.0). The integration of nine environmental indicators classification (accuracy: 0.87) yielded reliable municipal-level sustainability assessments. This granular approach enables more precise environmental impact estimation compared to state-level or binary certification metrics used in existing platforms.

Current digital tourism platforms (e.g., TripAdvisor, Google Travel) optimize primarily for user ratings and commercial partnerships, lacking explicit environmental criteria. Specialized sustainable tourism apps (e.g., Green Travelers, Ecobnb) provide directories of certified accommodation but do not optimize multi-destination itineraries. Our system bridges this gap by integrating sustainability assessment directly into the route optimization process. The 47% distance reduction achieved by ACO compared to popularity-based selection demonstrates that sustainability and efficiency are complementary rather than competing objectives. This finding challenges the common assumption that eco-friendly travel necessitates significant convenience trade-offs.

**5) Conclusion**

This research presents a Progressive Web Application using Ant Colony Optimization for sustainable tourism itineraries in Mexico. The system successfully integrates environmental responsibility with personalized recommendations through multi-criteria optimization (sustainability 40%, user ratings 20%, distance efficiency 20%, destination diversity 20%).

Key contributions include municipal-level sustainability assessment, real-time carbon footprint calculation, and prioritization of certified sustainable accommodations. Results show 47% distance reduction and convergence within 35 iterations, validating the approach's effectiveness.

The PWA empowers tourists to make informed decisions through transparent comparison between standard and sustainable itineraries, advancing responsible tourism aligned with Mexico's National Sustainable Tourism Strategy. The methodology is transferable to other regions, providing a framework for sustainable tourism development globally.

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**8] Data Availability:**

No new data were created or analyzed in this study. Data sharing is not applicable to this article

**9] Conflict of interest:**

The authors declare that there is no conflict of interest

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