ORIGINAL ARTICLE

lajss.org Latin American Journal of Solids and Structures

www.lajss.org

Dynamic Behavior and Natural Frequency of a Geodesic Dome: A Comparative Analysis of Physical and Computational Models Utilizing Recycled Plastic

Pablo Esteban Ramos Coronel[a]*, Eduardo Dioney Palma Zambrano[a], Daiana Cristina Metz Arnold[b]

[a]Universidad Católica de Cuenca, Department of Civil Engineering, (Cuenca, Ecuador). Email: peramosc64@est.ucacue.edu.ec, eduardo.palma@ucacue.edu.ec
[b]Universidade Feevale, Department of Civil Engineering, (Rio Grande Do Sul, Brasil). Email: daim@feevale.br

* Corresponding author

https://doi.org/10.1590/1679-7825/e8463

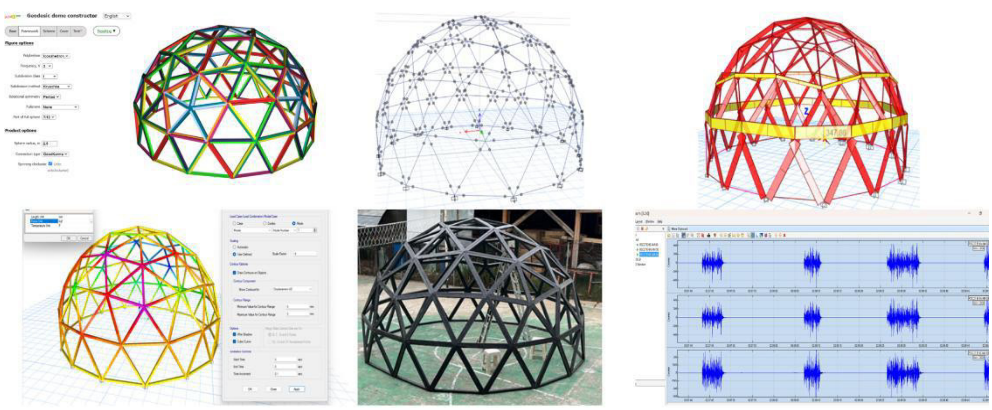
Abstract

This study investigates the dynamic behavior and natural frequency of a geodesic dome constructed with recycled polypropylene type 5, emphasizing its feasibility as a sustainable structural solution. A dual approach combining computational modeling and experimental testing was implemented. The computational model incorporated the material's mechanical properties and was validated against a physical prototype subjected to vibration tests. Results revealed a strong correlation between experimental and analytical data, with minimal discrepancies attributed to model idealizations and real construction conditions. The dome's structural performance demonstrated high rigidity and efficient load distribution, confirmed by short vibration periods and balanced dynamic responses. This research highlights the potential of recycled plastic in geodesic structures, aligning with circular economy principles by promoting material reuse and reducing environmental impact. The findings provide valuable insights into innovative and sustainable construction practices, supporting the integration of recycled materials in dynamic structural applications.

Keywords

Geodesic Domes, Recycled Plastics, Lightweight Structures, Structural Simulations, Modal Analysis

Graphical Abstract



1 INTRODUCTION

In a world where concerns about environmental impact and the depletion of natural resources are paramount, the construction industry is under increasing pressure to adopt sustainable practices (Hernández-Zamora et al., 2021). Plastic

Received November 21, 2024. In revised form February 01, 2025. Accepted February 26, 2025. Available online February 28, 2025.
https://doi.org/10.1590/1679-7825/e8463

waste, a byproduct of the industrial revolution, has become a critical global issue due to its extensive production and limited recycling capabilities. (Geyer et al., 2017). Consequently, rethinking construction methods by incorporating recycled materials has emerged as a pivotal strategy for reducing the environmental footprint of the sector.

Geodesic domes, known for their efficient geometry and ability to evenly distribute loads, represent a promising solution for addressing these challenges. These structures not only offer structural efficiency but also provide opportunities to repurpose waste materials, such as recycled plastics, into functional and sustainable components (Braida, 2020). Research has shown that geodesic domes made from alternative materials can exhibit comparable or even superior performance to traditional steel-based counterparts, particularly in terms of resilience to adverse environmental conditions (Abdulhameed et al., 2021). Moreover, recent advances in engineering have emphasized the importance of evaluating the structural dynamics of reticulated domes under vibratory and impact loads, offering valuable insights into their behavior under real-world conditions(Wei & Hu, 2019). These insights reinforce the potential of geodesic domes as innovative and sustainable architectural solutions, aligning with global efforts to mitigate environmental degradation through efficient structural designs (Kibert, C. J., 2016).

The urgency of adopting sustainable construction methods is particularly evident in Ecuador, where increasing plastic waste threatens ecosystems and communities (Portilla-Jiménez, 2022). This problem is compounded by excessive plastic consumption and the lack of effective recycling practices, which contribute to environmental degradation on an alarming scale. In Ecuador, as in many other regions of the world, the widespread production and use of plastics generate tons of waste that endanger local ecosystems and disrupt ecological balance (López-Aguirre & López-Salazar, 2020). In response, the tourism industry in Cuenca has embraced the use of geodesic domes as an innovative form of accommodation, particularly in areas like Challuabamba, where *glamping* initiatives provide tourists with eco-friendly lodging options that blend comfort and sustainability (Naula, 2023). These domes, often constructed with plastic materials, offer greater resistance to adverse weather conditions compared to traditional steel ones, making them an ideal choice for protecting natural environments (El Mercurio, 2020). For instance, in the Boquerón region, geodesic domes have been employed to create unique outdoor experiences, showcasing the use of recycled materials in environmentally friendly tourism infrastructure (Pazán, 2024)

This study investigates the dynamic behavior and natural frequency of a geodesic dome constructed with recycled polypropylene type 5. The computational model was developed using specialized engineering software such as Acidome (*ACIDOME*, 2024) and CADRE (CADRE, 2024), which allowed the creation of accurate models of a frequency 3 geodesic dome. Modal analysis was employed to simulate the dynamic response of the structure, focusing on its natural frequencies and periods. Experimental tests, including impact and vibratory load analyses, were conducted to validate the computational results, ensuring consistency between theoretical predictions and real-world behavior. This approach integrates computational advancements and experimental methods, reflecting current trends in sustainable construction research (Abdulhameed et al., 2021). The primary objective is to assess the feasibility of recycled plastic as a sustainable construction material, providing valuable insights into its potential applications in structural design. This multidisciplinary approach not only validates the material's performance but also highlights the structural advantages of geodesic domes in innovative engineering contexts (Pérez, 2018).

2 MATERIALS AND METHODS

2.1 Computational Modeling

For the computational modeling phase, engineering software such as Acidome (ACIDOME, 2024) and CADRE (CADRE, 2024) were used to generate accurate models of a frequency 3 geodesic dome. Acidome was selected for its open-source nature and its ability to generate the geometric configuration of a frequency 3 geodesic dome, simplifying the construction process by eliminating the need for connectors and reducing costs. This tool was used to ensure the accurate design of the dome's sections and overall structure, enabling practical construction applications. In contrast, CADRE was employed for analytical modeling, providing a precise representation of the dome's geometry by allowing the input of specific parameters, such as radius, frequency, and type, as illustrated in Figure 2. CADRE's output was then compared to the Acidome model to validate the geometric consistency. Additionally, CADRE enables the export of the analytical model in .dxf format, which was subsequently imported into ETABS® to perform the structural analysis, including modal and static evaluations, ensuring an accurate assessment of the dome's dynamic behavior and structural integrity. The selection of a frequency 3 dome was based on its optimal balance between structural simplicity and construction efficiency; a frequency 2 dome would not provide sufficient structural challenge, while a frequency 4 dome would significantly increase complexity and required resources. This choice aligns with recent studies emphasizing simplified designs that maintain structural efficiency while reducing material use (Abdulhameed et al., 2023).

The designed geodesic dome model is based on a frequency 3 icosahedral polyhedron with a type I subdivision, using the Kruschke method. This model features five-dimensional rotational symmetry and covers 7/12 of a sphere with a radius of 2.70 meters, without additional circumscription; the radius size was chosen considering the available space and resources for construction. The GoodKarma system was used for connections, a method that does not require metal connectors, facilitating construction and reducing costs (Mario, 2019). The dimensions of the structural elements used in the dome are square sections of 50 × 50 mm, as shown in Figure 1. These measurements were determined considering the mechanical properties of the material and the results obtained from the structural analysis. This approach aligns with studies emphasizing the significance of simplified models for evaluating both scaled and full-scale structural performance (Wei & Hu, 2019).

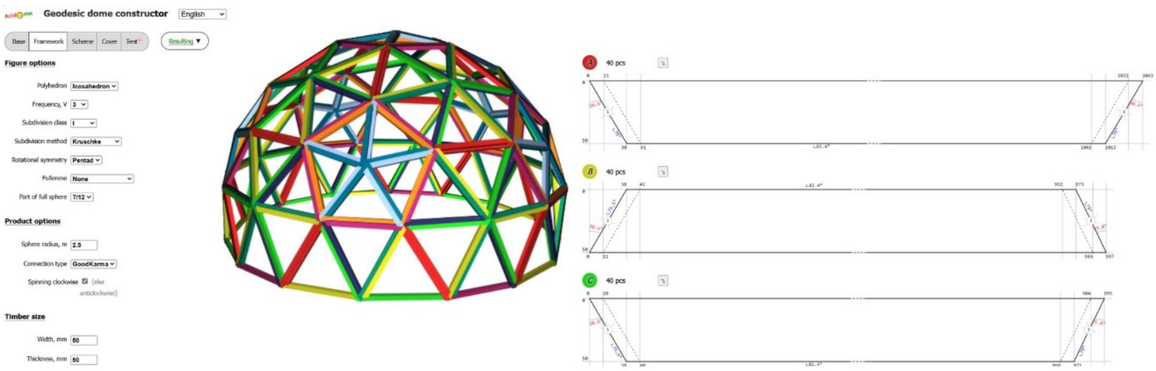


Figure 1 *Geodesic dome model and assembly geometry using the software provided by www.acidome.ru.*

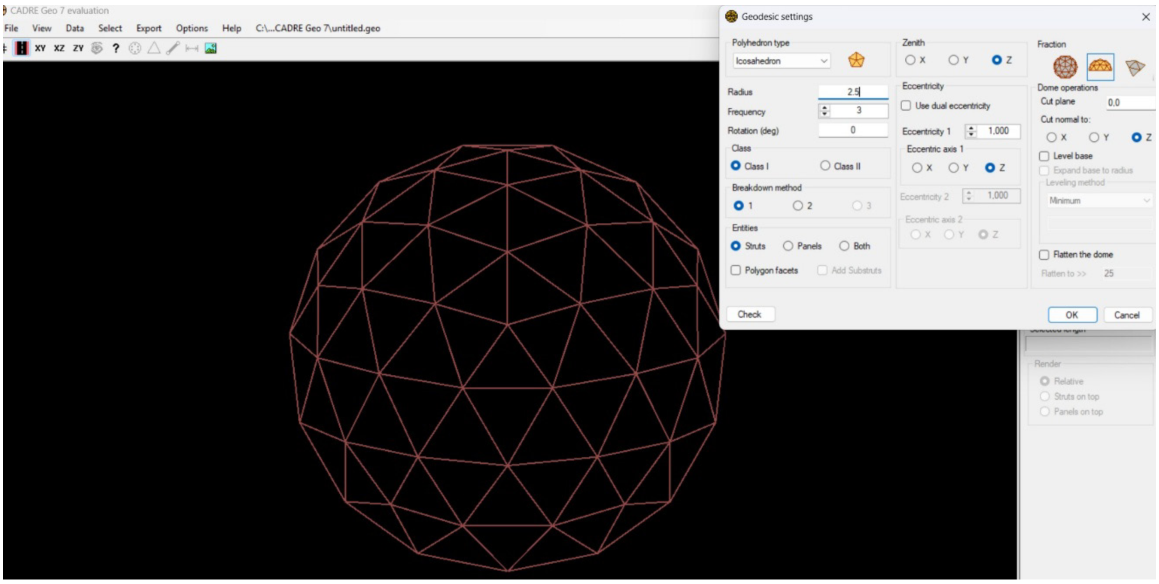


Figure 2 *Analytical model of the geodesic dome generated using the software provided by* www.cadreanalytic.com/cadregeo.htm

2.2 Analytical Model and Structural Analysis

The structural analysis was carried out in two main stages. The first stage corresponded to a static analysis, aimed at determining the size of the cross-sections based on the external loads applied to the dome and the mechanical properties of the material used. The second stage involved a dynamic analysis, specifically a modal analysis, which allowed for obtaining the natural period or frequency of the structure. For this second stage, only the mass of the dome was considered as the modal mass, without including contributions from additional live or dead loads, as the test was conducted with the dome without coverings or complementary elements.

In the structural analysis phase, specialized software ETABS® (CSI, 2022), was used, integrating the specific mechanical properties of recycled polypropylene. These properties include the material's tensile and compressive strength, as well as its modulus of elasticity and other parameters required by the software. The values for these properties were taken from the research titled "Mechanical Properties of Recycled Plastics and Tires", which can be seen in Table 1 and Figure 3 (Ramos Coronel et al., 2023). The integration of ETABS® for modal and static analysis is consistent with global trends in advanced structural modeling, as noted by studies like those of Abdulhameed et al. (2021) and Wei & Hu (2019).

***Table 1** Mechanical and Physical Properties of Recycled Plastic and Tires, taken from*

Material	$E_{compression}$	$E_{tension}$	G_{shear}	**n Poisson**	$s_{compression}$	$s_{tension}$	s_{shear}	$\rho_{density}$
	Mpa	**Mpa**	**Mpa**	**-**	**Mpa**	**Mpa**	**Mpa**	**g/cm^3**
Type 2 plastic	429.99	544.25	36.4	0.27	16.41	18.99	1.82	0.68
Type 5 plastic	576.32	N/A	46.59	N/A	14.51	19.55	3.19	0.66
Used tires	N/A	144.41	N/A	N/A	N/A	38.73	N/A	N/A

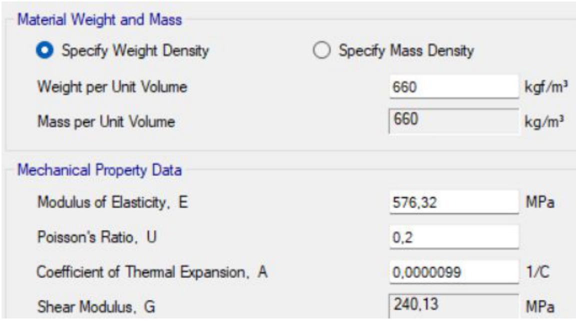


***Figure 3** Input of Material Properties for Polypropylene Type*

In the analysis of a geodesic dome, it is common to release the moments at the nodes or ends of the structural elements, modeling these connections as hinged, as shown in Figure 4. This reflects the typical behavior of the structure, composed of multiple triangular elements that primarily work under axial forces, such as compression and tension. By releasing the moments, the performance of the elements is optimized, allowing them to function more efficiently, similar to the behavior of a truss.

This geometric configuration promotes the uniform distribution of loads along the components of the dome, minimizing bending stresses and maximizing axial strength. This approach ensures efficient use of the material, aligning with the inherent design principle of geodesic domes, where axial forces predominate, and structural deformations remain within acceptable limits. Recent work has shown that such configurations are optimal for reducing bending stresses, particularly in lightweight structures using recycled materials (Bamaga et al., 2019).

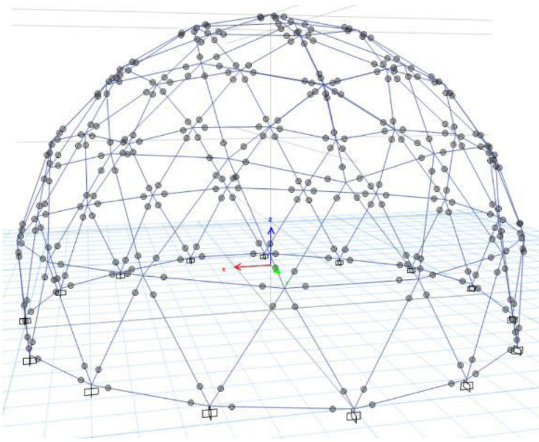


***Figure 4** Hinged Connections in ETABS®*

Given that the primary objective of the structure is research, idealized loads were applied to determine the stresses in the elements and based on this, to size the structural profiles. In this case, a live point load of 70 kg was considered at each node of the dome, representing the weight of a person at that point. Additionally, a dead load of 15 kg per node was included, simulating the weight of permanent elements, such as a potential dome covering.

The applied loads were oversized to ensure a safe design that includes an additional safety margin. This ensures that the designed cross-sections are capable of withstanding extreme conditions and preventing potential rigidity and stability issues in unusual situations. The load application points are shown in Figure 5.

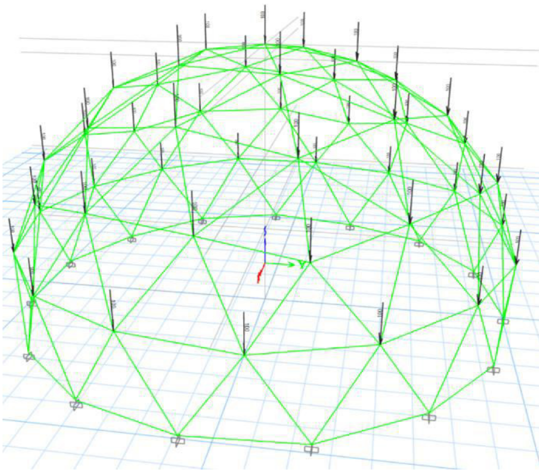


Figure 5 *Point Loads Applied at the Nodes of the Dome*

The supports were set as simply supported, except for one, which was modeled as hinged to ensure the analytical stability of the structure. The analysis conducted with ETABS® provided precise data on the demands on the structural elements, which were predominantly axial compression forces (represented in red) and tension forces (represented in yellow), as shown in Figures 6, 7, and 8.

To define the cross-sections of the elements, the maximum demands obtained, both in tension and compression, were considered, ensuring that the selected dimensions met the structural requirements and guaranteed the proper performance of the dome.

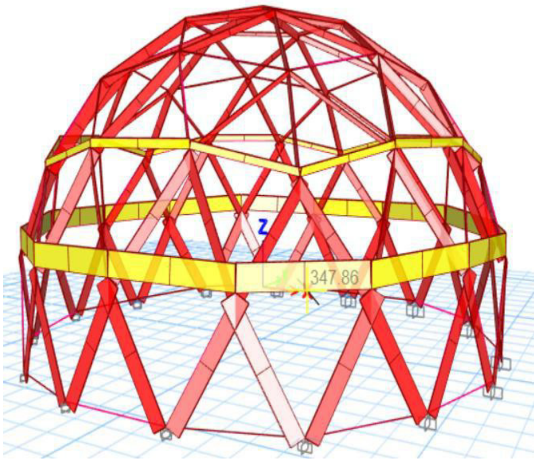


Figure 6 *Axial Forces Obtained in Structural Analysis Software ETABS®*

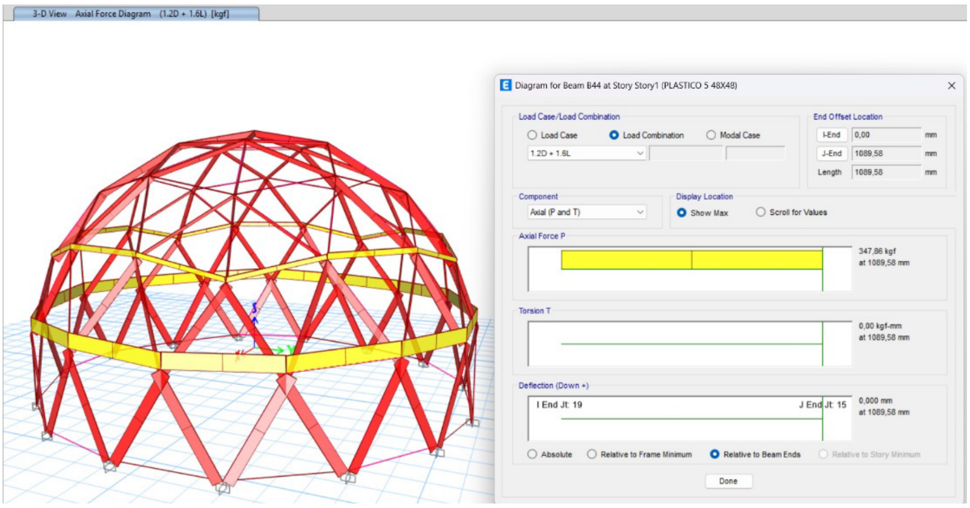


Figure 7 *Maximum Axial Forces in Structural Analysis Software ETABS® for Tension Elements.*

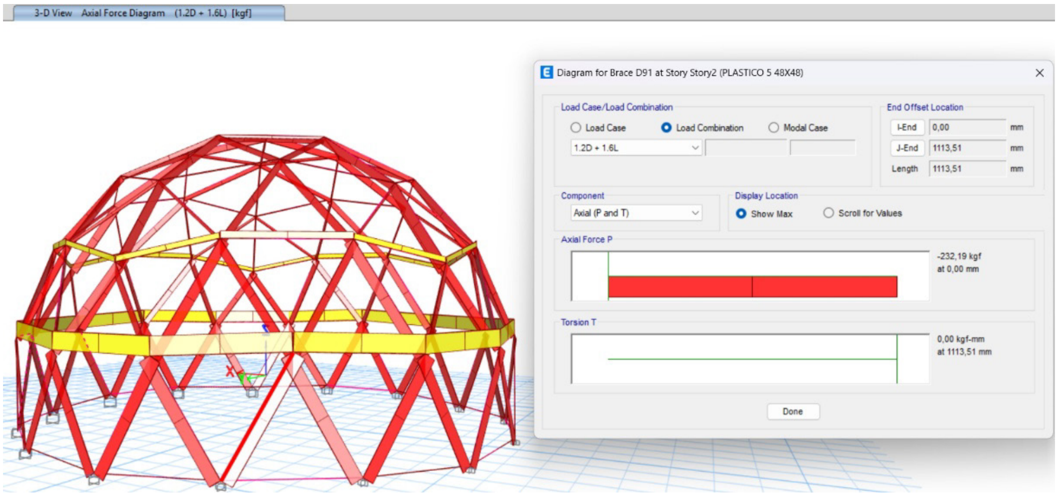


Figure 8 *Maximum Axial Forces in Structural Analysis Software ETABS® for Tension Elements*

2.3 Definition of Sections

The recycled plastic used in this study exhibits low rigidity, which causes it to buckle under compressive loads before reaching its compression limit, behaving like a long column, as shown in Figure 9 (Rekha M & Kalurkar, 2014).

Figure 9 *Example of Lateral Torsional Buckling in a Tested Structural Element*

Due to the presence of lateral torsional buckling observed in subsequent tests, Euler's buckling formula was used for sizing the compression elements, assuming that the ends of the elements are hinged and operate within the elastic range of the material.

To ensure that the material operated within this range, the Euler critical load (Pe) was calculated, and a sufficiently large cross-section was selected to keep the stresses below this critical value. Calculations determined that the required cross-section for the compression elements was a square section of 50 × 50 mm, while for the tension elements, a section of 14.2 × 14.2 mm was needed. However, for construction reasons, particularly related to connectivity between elements, the larger square section of 50 × 50 mm, defined by the compression demands, was chosen to ensure structural stability and assembly simplicity.

Euler's buckling formula was used for the analysis of the compression structural sections, considering hinged-hinged support conditions and stresses within the elastic range. The formula is expressed as:

$$\mathrm{Fe} = \frac{\pi^2 E}{\left(\frac{L}{r}\right)^2} = \frac{\mathrm{Pe}}{\mathrm{A}} \tag{1}$$

Where: Fe represents Euler's critical stress, r is the minimum radius of gyration, L is the distance between inflection points, E represents the modulus of elasticity of the material and Pe is the critical load at which the column begins to buckle.

Sizing of the Compression Element

$$E = 5876.83 \frac{kgf}{cm^2} \; L = 1.09\, m \; b = 0.05\, m \; h = 0.05\, m$$

$$A = b * h = 0.0025\, m^2 \tag{2}$$

$$I = \frac{b*h^3}{12} \tag{3}$$

$$r = \sqrt{\frac{I}{A}} = 0.01443\, m \tag{4}$$

$$Pe = \frac{\pi^2 * E}{(\frac{L}{r})^2} * A = 254.453\, kgf > 231 kgf\ ETABS \tag{5}$$

Where: E represents the modulus of elasticity, L is the length of the element, b is the base of the element, h is the height of the element, A denotes the cross-sectional area, and I is the moment of inertia of the section.

Sizing of the Tension Element

$$\boldsymbol{F_{tension} = 391.77\, kgf\ ETABS}$$

$$\sigma_{admissible} = 19.55\, MPa$$

$$A_{min} = \frac{F_{tension}}{\sigma_{admissible}} = 1.965\, cm^2 \tag{6}$$

$$b = side = \sqrt{A_{min}} = 1.402\, cm \tag{7}$$

Where: $F_{tension}$ represents the maximum tensile force in the structure provided by the structural analysis software, $\sigma_{admissible}$ is the allowable stress of type 5 plastic (polypropylene) and b is the side of the section.

2.4 Natural Frequency of the Dome, Analytical Model

The verification of vibration periods was carried out through a modal structural analysis using the specialized software ETABS®. This analysis allowed the identification of the fundamental vibration period of the structure, which was approximately 0.0722 seconds in the X and Y axes. Additionally, other relevant parameters were evaluated, such as tensile and compressive stresses, displacements, and the overall behavior of the dome under various loading conditions. This comprehensive approach confirmed the stability and integrity of the structure, demonstrating that the designed structural elements are capable of safely and efficiently withstanding the applied loads. The detailed results of this analysis are presented in the following section; Figure 10 shows the deformation of the structure through modal analysis (Shivani K et al., 2023).

According to Chopra, natural vibration properties such as natural circular frequency (ωn), natural period (Tn) and natural cyclic frequency (fn) depend exclusively on the mass and stiffness of the structure. This implies that, in systems with the same mass, greater stiffness leads to a shorter natural period, while a structure with greater mass exhibits a longer natural period. These properties are inherent to the system and manifest when it vibrates freely, without the influence of external excitations, being independent of the initial conditions of displacement and velocity (Chopra, 2014).

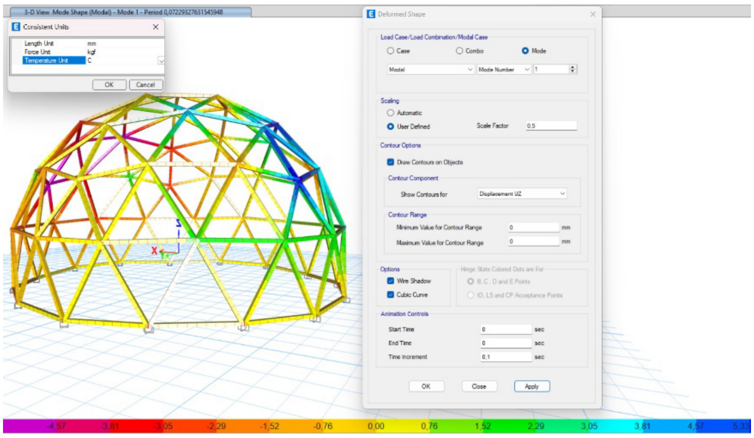


Figure 10 *Deformation of the Structure through Modal Analysis*

Modal Periods And Frequencies

File Edit Format-Filter-Sort Select Options

Units: As Noted Hidden Columns: No Sort: None Modal Periods And Frequencies

Filter: None

Case	Mode	Period sec	Frequency cyc/sec	CircFreq rad/sec	Eigenvalue rad²/sec²
Modal	1	0.0723	13.833	86.9124	7553.7729
Modal	2	0.0706	14.171	89.0407	7928.2537
Modal	3	0.0499	20.021	125.7958	15824.5948

Figure 11 *Periods of the Structure in Each Mode of Vibration*

Figure 11 indicates that the first two vibration modes have similar periods, which is consistent with the symmetrical design of the geodesic dome. These results reflect a uniform distribution of stiffness and mass, confirming the effectiveness of the developed structural model. The similarity in the periods suggests that the structure responds in a balanced manner in the X and Y axes, a characteristic behavior of well-designed systems.

The third mode, with a shorter period and a higher natural frequency, demonstrates the dome's capacity to handle faster movements, reinforcing its rigidity and stability against dynamic excitations. This behavior confirms that the design and material selection achieve the expected performance, ensuring both safety and structural efficiency.

The short periods observed in the analysis indicate a light and rigid structure, demonstrating the capacity to respond rapidly to external demands. These results validate the quality of the computational model, and the analytical approach adopted, positioning the dome as an innovative, efficient structural solution adaptable to various loading scenarios.

2.5 Construction of Sections and Dome Assembly

In the construction phase, type 5 recycled polypropylene was used, which was subjected to a shredding process to obtain uniform and homogeneous fragments (Figure 12). This procedure was essential to ensure the proper preparation of the material, facilitating its subsequent processing and ensuring the quality and consistency needed for producing the structural elements of the dome. The uniformity of the shredded material not only optimized the extrusion of the structural sections but also helped maintain the mechanical properties of the polypropylene, which are essential to meet the structural design requirements.

Subsequently, the type 5 recycled polypropylene fragments were processed through extrusion using a high-precision extruder, as shown in Figure 13. Extrusion not only ensures that the recycled material acquires the desired shape but also maintains dimensional consistency and strictly adheres to the structural design specifications, guaranteeing the quality required to withstand the expected loads in the structural analysis.

For the construction of the dome sections, a Grade 50 steel mold (Figure 14) with dimensions of 50 × 50 × 5 mm and a length of 2.15 m was manufactured. This material was chosen for its high mechanical strength and its ability to withstand the high temperatures involved in the recycled plastic extrusion process, ensuring the mold's durability and precision. During extrusion, the recycled polypropylene is exposed to extreme temperatures that could cause deformations in molds made from less robust materials. The use of Grade 50 steel ensures that the mold maintains its shape throughout the process, enabling the production of uniform, high-quality structural elements essential for ensuring the integrity and performance of the geodesic dome.

Figure 12 *Shredded Type 5 Plastic (Polypropylene)*

Figure 13 *High-Precision Extruder.*

Figure 14 *High-Precision Extruder.*

In Figure 15, the extruded elements can be seen, showing their final shape and dimensions.

Figure 15 *Result of the Polypropylene Extrusion, Elements with 50 × 50 mm Section and 2.15 m Length.*

The structural pieces were precisely cut using a miter saw, following the dimensions specified by the Acidome software. The sections, measuring 50 × 50 mm, were connected using 3 × 50 mm screws to form triangular modules, as shown in Figure 16. These screws were selected for their mechanical resistance and ensured uniform load distribution and structural stability. The pre-drilled holes in the profiles were critical to guaranteeing proper alignment during assembly, optimizing the maneuverability and precision of the process (Flores Gutiérrez & Claure Gantier, 2016).

Figure 16 *Connection of Elements to Form the Triangles of the Frequency 3 Dome.*

Once the triangular modules were constructed, they were assembled into the geodesic dome using 5-inch bolts, ensuring a secure and reliable connection. This bolted system facilitated the integration of the triangular units into the dome's distinctive geometry, leveraging the inherent stability of triangular structures to evenly distribute axial forces, such as compression and tension, across the entire structure.

Figures 17 and 18 illustrate the construction process, highlighting the assembly of the first strip of the dome and the structure at 50% completion. The final dome, constructed from recycled polypropylene plastic, demonstrated the material's feasibility for geodesic applications while maintaining structural integrity under various loads.

Figure 17 *Assembly of the first strip and Dome at 50% completion.*

Figure 18 *Geodesic dome with recycled polypropylene plastic elements.*

2.6 Dynamic Testing and Structural Response Assessment

Once the construction of the dome was completed, a Raspberry Shake 3D device, shown in Figure 19, was used as a measurement instrument to conduct vibration tests, aimed at evaluating the dynamic response of the structure. These tests included applying various external excitations that generated initial deformations in the dome, which, upon ceasing, allowed the structure to vibrate freely. As shown in Figure 20, the excitation techniques included manual impacts applied to specific nodes of the dome using a wooden log, simulating horizontal forces acting on the structure. Each impact was directed to induce vibrations and ensure consistent and controlled excitation across the dome. Additionally, a vertical load of 105 kg was applied at the apex of the dome by suspending a person from the peak and subsequently releasing them to allow free vibration. These controlled excitations simulated both horizontal and vertical loading conditions, providing a comprehensive evaluation of the dome's dynamic behavior under real-world scenarios. The data obtained during these experimental tests were used to validate and compare the results with the previously developed analytical model. This analysis allowed the verification of the consistency between the natural frequencies calculated using the software and the in-situ recorded responses, demonstrating the model's capability to accurately predict the dome's dynamic behavior. The positive correlation between experimental and analytical data reinforces the model's reliability and confirms that the dome's structural design meets theoretical expectations, highlighting it as an innovative and efficient solution for dynamic applications.

Figure 19 *Installation and location of Raspberry Shake 3D.*

Figure 20 *Impact Test on Nodes and Experimental Test to simulate a Vertical Load.*

Once the data captured by the Raspberry Shake 3D was extracted using FileZilla software, it was loaded into SWARM software, which facilitates the visualization and extraction of seismographic signals, as shown in Figure 21.

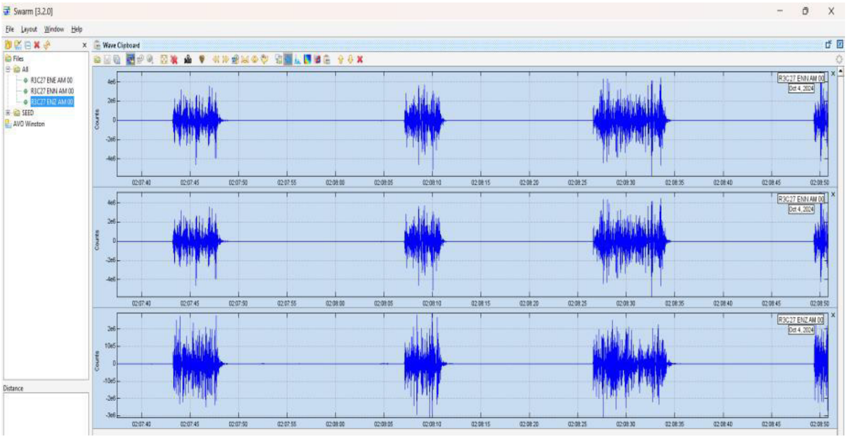


***Figure 21** Signals Loaded in SWARM Software.*

From this interface, the complete signal was extracted, maintaining a 0.01-second time interval to ensure the necessary resolution for a detailed analysis of the structure's dynamics.

To convert the readings from “counts” to acceleration values (in m/s^2), the conversion factor provided by the device was used, dividing each reading by 386,825. This conversion is crucial for interpreting the data in real physical terms and allows for a direct comparison with the theoretical results obtained from the model (Huiñisaca Quishpe et al., 2023).

Once converted, the data was imported into Geopsy software for an analysis of the vertical, north, and east components of the signals. In Geopsy, the H/V (horizontal/vertical) method was employed to obtain the natural vibration frequency of the dome, evaluating the signal characteristics over time and acceleration, as shown in Figure 22 (Wathelet et al., 2020).

This analysis provided both the frequency and the natural period of the structure, where the period was obtained by taking the inverse of the measured frequency. These values help assess the stiffness and dynamic properties of the dome, verifying that the structure responds according to the theoretical parameters set in the design model.

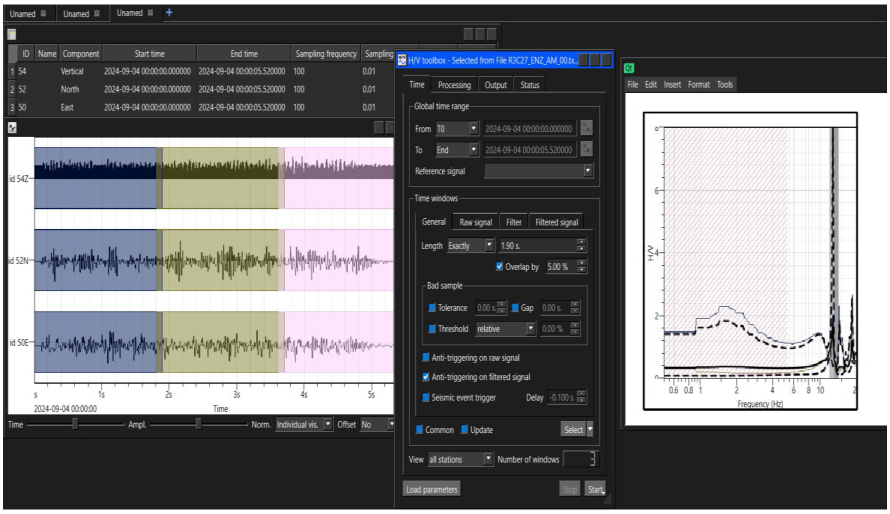


***Figure 22** Analysis of Vibration Components and Frequency Spectrum in Geopsy Software.*

During the signal processing phase, a script was created in MATLAB that performs successive numerical integrations using the cumulative trapezoidal integration method (cumtrapz). First, the filtered acceleration signal was integrated with respect to time to obtain the velocity. This operation accumulates the area under the acceleration curve, translating changes in acceleration to variations in velocity, which reflects the short-term dynamic response of the structure.

Then, a second integration of the velocity signal was performed, also with respect to time, to calculate the displacement. This step sums the instantaneous velocities over time, providing the path of motion of the dome under dynamic excitation. The numerical integrations allow the analysis of structural behavior in terms of accumulated displacements, a key parameter for comparing theoretical results and validating the stability and rigidity of the structural model, as shown in Figure 23 (Hidalgo, 2024).

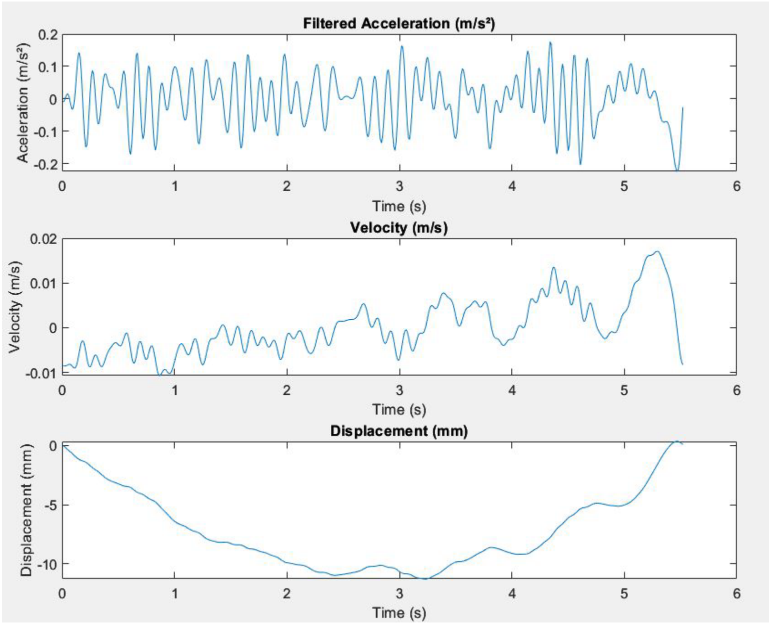


Figure 23 *Graphs of Filtered Acceleration, Velocity, and Displacement of the Geodesic Dome Over Time*

3 RESULTS AND DISCUSSION

3.1 Comparison Between the Analytical and Computational Models

The modal structural analysis of the geodesic dome allowed for the comparison of the natural frequencies obtained experimentally with those calculated using the computational model. Using the Raspberry Shake 3D device, acceleration signals were recorded during the vibration tests, which were processed to extract parameters such as acceleration, velocity, and displacement.

The fundamental period obtained from the experimental data was 0.0777 seconds, while the computational model predicted a period of 0.0722 seconds, as shown in Table 2. This slight discrepancy is attributed to idealizations in the computational model, such as the possible simplification of structural details and the omission of certain damping effects inherent to the physical structure. However, the proximity of these results validates the model, demonstrating its capability to adequately represent the dynamic behavior of the dome.

Table 2 Comparison of Modal Periods and Frequencies

Analytical Model (ETABS)	**Physical Model (In-Situ Test)**		
Frequency (Hz)		**Type of Excitation**	**Frequency (Hz)**
13.833	**Test 1**	Point load 105 kg	14.0428
	Test 2		14.7537
	Test 3		14.0428
	Test 4		12.4118
	Test 5		12.4118
	Test 6	Horizontal impacts on nodes	13.7003
	Test 7		11.5256
	Test 8		11.5256
	Test 9		12.7221
	Test 10		12.1091
	Test 11		12.4118
	Average		12.8779
Period = 0.0722 s	**Period**		0.0777

3.2 Signal Processing and Applied Filter Analysis

During the processing of the captured signals for vibration analysis, a high-pass filter with a 10 Hz threshold was applied. This filter eliminates low-frequency components and noise that could interfere with the structure's true dynamic response, allowing focus solely on frequencies above this limit, which contain relevant information for the dome's vibratory behavior (Sandoval & Vera, 2013).

In Geopsy software, a Butterworth filter configured with a cutoff frequency range between 1 and 20 Hz was used for the H/V analysis. This type of filter is ideal due to its uniform response in the passband, preserving relevant frequencies without alterations until the cutoff frequency, where it gradually attenuates them. This characteristic allows Geopsy to focus solely on the frequency range that provides significant information about ground resonance, removing noise outside this interval. This approach enables a more precise identification of the system's fundamental frequency, optimizing the analysis interpretation (Sandoval & Vera, 2013).

Additionally, the Hamming method was used in the signal preprocessing. This method smooths discontinuities at the signal boundaries, improving the accuracy of critical parameter estimation such as frequency and period. The Hamming window is a mathematical function that progressively attenuates the data edges, minimizing abrupt discontinuities or 'jumps' at the signal edges. This is crucial for obtaining reliable measurements of the dome's dynamic response (Podder et al., 2024).

3.3 Vulnerability to Settlement

Certain complementary variations were made in the structural analysis of the dome. One of the most relevant observations was that applying a displacement at one of the supports significantly increased internal forces, particularly axial tensile and compressive forces. For this case, a displacement in the Z direction of 20 mm was induced, which caused an amplification of internal forces up to four times compared to normal loading conditions.

This increase in stresses highlights the importance of having a foundation that minimizes differential settlements at the dome's supports. Any displacement at the supports can induce additional deformations and an undesirable redistribution of loads in the structure. Without ensuring the necessary foundation rigidity, the dome's stability could be compromised, increasing the risk of collapse due to the uncontrolled concentration of forces in specific elements.

As detailed in section 2.3, the structural sections were designed to withstand a maximum tensile force of 254 kgf. However, under induced displacement conditions, some axial forces exceeded this limit, reaching values close to 1044 kgf, as shown in Figure 24. This shows that, although the element design is suitable for normal conditions, it may be insufficient in scenarios where displacements occur at the supports. These results underline the need to ensure foundation rigidity to preserve the dome's structural integrity and prevent potential failures under adverse conditions.

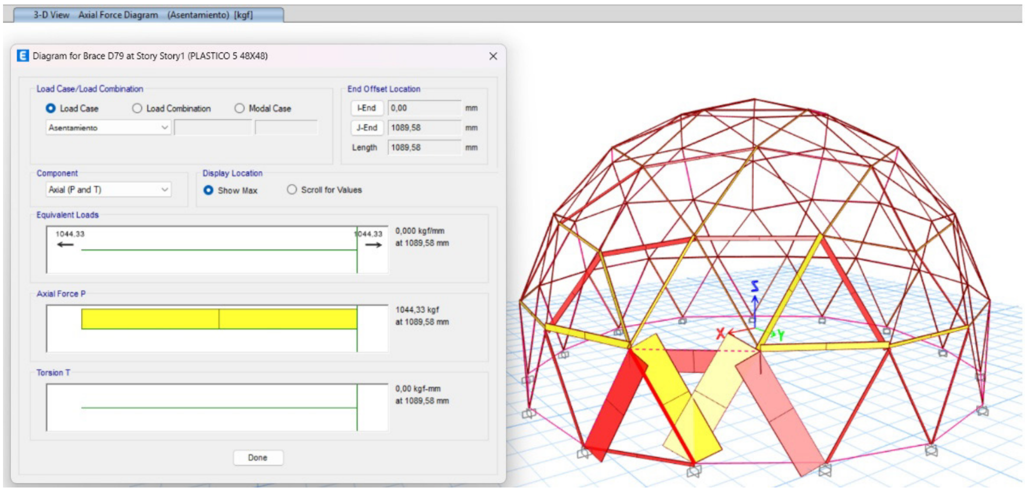


Figure 24 *Axial Forces Under Settlement Conditions*

4 CONCLUSIONS

This research validates the structural feasibility of geodesic domes constructed with type 5 recycled polypropylene, highlighting both their dynamic performance and potential for sustainable applications. The results obtained emphasize the inherent advantages of this structural typology, characterized by its efficient geometry based on triangles, which allows for uniform load distribution and ensures the rigidity of the structure under dynamic demands.

The dynamic analysis, both experimental and computational, showed that the low vibration periods obtained reflect the high rigidity of the dome. The computational modeling conducted using ETABS® included a modal analysis, which predicted a fundamental period of 0.0722 seconds for the structure. These results were validated through experimental vibration testing. The H/V spectral ratio analysis, performed using Geopsy software, determined the natural vibration period of 0.0777 seconds. The close agreement between computational predictions and experimental findings confirms the reliability of the computational model in capturing the dome's dynamic behavior.

Recycled polypropylene exhibited adequate mechanical properties to sustain static and dynamic loads. To mitigate the material's inherent low rigidity, cross-sectional dimensions were optimized to prevent buckling under compression, demonstrating its applicability for lightweight and sustainable structures.

The geodesic dome's geometry efficiently distributed loads through axial forces, minimizing bending stresses and ensuring structural stability. This underscores the structural advantages of geodesic designs in achieving material efficiency and uniform load distribution.

Simulated vertical displacement at the supports (20 mm) significantly increased axial forces, amplifying internal stresses up to four times. This finding highlights the importance of rigid foundations to minimize differential settlements and prevent stress concentrations that could compromise the dome's structural integrity.

A combination of computational tools (Acidome, CADRE, and ETABS®) and H/V spectral analysis ensured a robust evaluation of the dome’s dynamic performance. The integration of computational modeling and experimental validation techniques reinforced the reliability of the study’s findings.

Using recycled polypropylene aligns with circular economy principles by reducing environmental impact and offering an economical alternative to traditional construction materials. This research validates the potential of recycled plastic for medium-scale dynamic structures and contributes to advancing sustainable construction practices.

While the study establishes the feasibility of using recycled polypropylene in dynamic structures, certain limitations must be acknowledged. Minor discrepancies between computational and experimental results may arise from model idealizations, such as rigid connections or exclusion of damping effects. Additionally, the impact of support displacements emphasizes the necessity of robust foundation design. Further research is needed to evaluate the long-term durability of recycled polypropylene under diverse environmental conditions.

The integration of computational modeling with H/V spectral analysis illustrates the robustness of the study’s methodology. The close alignment between theoretical predictions and experimental data underscores the reliability and precision of the research approach.

This study provides a foundation for the use of recycled materials in structural applications, particularly in lightweight and dynamic systems. Future research should explore the effects of environmental factors on the mechanical properties of recycled polypropylene, the scalability of geodesic dome designs for larger structures, and the integration of additional recycled materials to enhance structural performance.

In conclusion, this research demonstrates that geodesic domes constructed with recycled polypropylene are a viable, sustainable, and innovative solution for dynamic structural applications, contributing to advancements in circular economy-driven construction practices.

Acknowledgements

Special thanks to Gorky Cordova from the company Domos Cuenca, located in Cuenca, Ecuador, for his assistance and guidance in the construction of the dome.

This research was funded by the Universidad Católica de Cuenca under the project PIC5P23-31 titled “Development of Plastic Structures, Urban Furniture, Eco-friendly Clothing and Footwear through the Implementation of Circular Economy.”

Author’s Contribuitions: Methodology, Research (preparation and construction), Writing – original draft, Pablo Esteban Ramos Coronel; Supervision, Methodology, Writing - review & editing, Eduardo Dioney Palma Zambrano; Review, Daiana Cristina Metz Arnold.

Editor: Pablo Andrés Muñoz Rojas

References

Abdulhameed, A. A., Hanoon, A. N., Abdulhameed, H. A., Banyhussan, Q. S., & Mansi, A. S. (2021). Push-out test of steel–concrete–steel composite sections with various core materials: Behavioural study. *Archives of Civil and Mechanical Engineering, 21*(1), 17. https://doi.org/10.1007/s43452-021-00173-y

Abdulhameed, A. A., Hason, M. M., Sharba, A. A. K., Hanoon, A. N., Amran, M., Magbool, H. M., & Gamil, Y. (2023). Experimental and environmental investigations of the impacts of wood sawdust on the performance of reinforced concrete composite beams. *Case Studies in Construction Materials, 19*, e02550. https://doi.org/10.1016/j.cscm.2023.e02550

ACIDOME. (2024). [Software]. Recuperado 18 de noviembre de 2024, de https://acidome.com/lab/calc/#7/12_Kruschke_GoodKarma_3V_R2.7_beams_50x50

Bamaga, S. O., Tahir, M. M., Ngian, S. P., Mohamad, S., Sulaiman, A., & Aghlara, R. (2019). Structural Behaviour of Cold-Formed Steel of Double C-Lipped Channel Sections Integrated with Concrete Slabs as Composite Beams. *Latin American Journal of Solids and Structures, 16*, e195. https://doi.org/10.1590/1679-78255515

Braida, F. (2020). Geodésicas na arquitetura: da representação gráfica à construção em escala natural. *Revista Geometria Gráfica, 4*(1), 5. https://doi.org/10.51359/2595-0797.2020.245784

CADRE. (2024). CADRE Geo 7 (Versión 7.4) [Software]. CADRE Analytic. https://www.cadreanalytic.com/cadregeo.htm

Chopra, A. K. (2014). Dinámica de estructuras (4.ª ed.). Pearson Education.

CSI. (2022). ETABS (Versión 22) [Software]. CSI. https://www.csiespana.com/software/5/etabs#

El Mercurio. (2020, octubre 31). *El «glamping», una tendencia de lujo en Ecuador para tiempos de pandemia.* https://elmercurio.com.ec/2020/10/31/el-glamping-una-tendencia-de-lujo-en-ecuador-para-tiempos-de-pandemia/

Flores Gutiérrez, N. F., & Claure Gantier, G. (2016). Análisis y Diseño de una Estructura de Bambú Basada en el Domo Geodésico de Fuller Aplicación a Viviendas Económicas en Bolivia. *Journal Boliviano de Ciencias, 12*(38), 46-57. https://doi.org/10.52428/20758944.v12i38.666

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7), e1700782. https://doi.org/10.1126/sciadv.1700782

Hernández-Zamora, M. F., Jiménez-Martinez, S., Sánchez-Monge, J. I., Hernández-Zamora, M. F., Jiménez-Martinez, S., & Sánchez-Monge, J. I. (2021). Materiales alternativos como oportunidad de reducción de impactos ambientales en el sector construcción. *Revista Tecnología en Marcha, 34*(2), 3-10. https://doi.org/10.18845/tm.v34i2.4831

Hidalgo, A. (2024). Educación en Ingeniería Civil: evaluación de la rigidez y simetría en puentes de sección mixta. *Revista Conrado*, *20*(97), 207-217.

Huiñisaca Quishpe, A. S., Maldonado Noboa, J. S., & Maldonado Noboa, C. H. (2023). Modelización y evaluación sísmica de la torre izquierda de la iglesia “Santuario del Espíritu Santo y de Nuestra Señora de Guadalupe”. *MQRInvestigar, 7*(1), 2187-2209. https://doi.org/10.56048/MQR20225.7.1.2023.2187-2209

Kibert, C. J. (2016). *Sustainable Construction: Green Building Design and Delivery.* John Wiley & Sons.

López-Aguirre, J. F., & López-Salazar, J. L. (2020). Análisis de la contaminación ambiental por plásticos en la ciudad de Riobamba Analysis of environmental pollution by plastics in the city of Riobamba Análise da poluição ambiental por plásticos na cidade de Riobamba. *Polo del Conocimiento*, 5(12), 725-742. https://doi.org/10.23857/pc.v5i12.2139

Mario, T. (2019). *Domos Geodésicos Manual Completo de Construcción* (Vol. 1). Ediciones midomo. https://www.midomo.es/el-libro/

Naula, P. (2023, agosto 11). *Glamping, alojamiento al aire libre en Challuabamba.* https://elmercurio.com.ec/2023/08/11/glamping-alojamiento-al-aire-libre-en-challuabamba/

Pazán, C. (2024, febrero 8). Feriado de Carnaval: El Boquerón, una opción para disfrutar en Cuenca. Diario Extra.

Pérez, M. (2018). *Análisis estructural de domos geodésicos metálicos como alternativa a la demanda de unidades habitacionales tipo vivienda* [Universidad Técnica de Machala]. https://repositorio.utmachala.edu.ec/bitstream/48000/13276/1/T-2708_P%c3%89REZ%20RODR%c3%8dGUEZ%20MICHAEL%20BENIGNO.pdf

Podder, P., Zaman, T., & Haque, M. (2024). Comparative Performance Analysis of Hamming, Hanning and Blackman Window. *International Journal of Computer Applications*, *96*(18), 7. https://doi.org/10.5120/16891-6927

Portilla-Jiménez, J. G. (2022). Análisis del Marco Normativo de Economía Circular en Ecuador Orientado al Sector de los Plásticos. *FIGEMPA: Investigación y Desarrollo, 13*(1), 38-47. https://doi.org/10.29166/revfig.v13i1.3364

Ramos Coronel, P. E., Palma-Zambrano, E. D., & Martínez Fernández, J. A. (2023). Propiedades mecánicas de plásticos y neumáticos reciclados. *MQRInvestigar, 7*(1), 2053-2077. https://doi.org/10.56048/MQR20225.7.1.2023.2053-2077

Rekha M, B., & Kalurkar, L. G. (2014). Study of Buckling Behavior of Beam and Column. *IOSR Journal of Mechanical and Civil Engineering, 11*(4), 36-40. https://doi.org/10.9790/1684-11413640

Sandoval, V., & Vera, M. (2013). *Estudio de la robustez de la estimación espectral de la técnica H/V de Nakamura para estudios de caracterización de suelos.* http://cybertesis.uach.cl/tesis/uach/2013/bmfcis218e/doc/bmfcis218e.pdf

Shivani K, K., Abhay R, J., & Deepak P, P. (2023). Structural Analysis of Kiewitt Dome by using ETABS Software. *International Journal for Scientific Research & Development*, *10*(12), 23-28. https://www.ijsrd.com/articles/IJSRDV10I120079.pdf

Wathelet, M., Chatelain, J.-L., Cornou, C., Giulio, G. D., Guillier, B., Ohrnberger, M., & Savvaidis, A. (2020). Geopsy: A User-Friendly Open-Source Tool Set for Ambient Vibration Processing. *Seismological Research Letters, 91*(3), 1878-1889. https://doi.org/10.1785/0220190360

Wei, D., & Hu, C. (2019). Scaling of An Impacted Reticulated Dome Using Partial Similitude Method. *Latin American Journal of Solids and Structures, 16*, e158. https://doi.org/10.1590/1679-78255342