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AERODYNAMIC ANALYSIS OF TEMPORARY SHELTERS: EVALUATION OF A GEODESIC DOME IN A DIGITAL WIND TUNNEL

ANÁLISE AERODINÂMICA DE ABRIGOS TEMPORÁRIOS: AVALIAÇÃO DE UM DOMO GEODÉSICO EM TÚNEL DE VENTO DIGITAL

ANÁLISIS AERODINÁMICO DE REFUGIOS TEMPORALES: EVALUACIÓN DE UN DOMO GEODÉSICO EN UN TÚNEL DE VIENTO DIGITAL

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ABSTRACT
The loss of housing triggered by natural disasters exposes vulnerable populations to precarious conditions, thereby necessitating the development of temporary shelters resilient to extreme weather events. This study aims to evaluate the structural aerodynamic resistance of a geodesic dome temporary shelter under high-intensity wind loads, comparing its performance against a conventional container-shaped structure. The methodology involved Computational Fluid Dynamics (CFD) simulations executed via RWIND software, replicating three scenarios derived from the Beaufort Scale: a strong gale (11 m/s), a storm (18 m/s), and a hurricane (33 m/s). The numerical results demonstrated the aerodynamic superiority of the geodesic dome, which dissipated airflow in a continuous and streamlined manner. Under a wind velocity of 33 m/s, the dome exhibited a horizontal drag force (Fx) of merely 2.497 kN. Conversely, the container reached a critical drag force of 4.599 kN, highlighting severe structural instability inherent to orthogonal geometries. In conclusion, the geodesic dome drastically mitigates aerodynamic impacts, proving to be a highly viable and secure solution for disaster-prone areas, provided that foundation sizing is adequately engineered to counteract vertical suction forces.

KEYWORDS: *Temporary Shelters. Aerodynamics. Wind Tunnel. Geodesic Dome. Natural Disasters.*

RESUMO
A perda de moradias por desastres naturais expõe populações vulneráveis a condições precárias, exigindo o desenvolvimento de abrigos temporários resistentes a eventos climáticos extremos. O objetivo deste trabalho é avaliar a resistência estrutural aerodinâmica de um abrigo temporário em formato de domo geodésico frente a ventos de alta intensidade, comparando-o com uma estrutura convencional em formato de contêiner. A metodologia consistiu em simulações de Dinâmica de Fluidos Computacional (CFD) utilizando o software RWIND, simulando três cenários baseados na Escala de Beaufort: vento forte (11 m/s), tempestade (18 m/s) e furacão (33 m/s). Os resultados demonstraram a superioridade do domo, que dissipou o fluxo de ar contínua e suavemente. Sob ventos de 33 m/s, o domo registrou uma força de arrasto horizontal (Fx) de apenas 2,497 kN, enquanto o contêiner atingiu críticos 4,599 kN, evidenciando instabilidade estrutural severa da geometria ortogonal. Conclui-se que o domo geodésico reduz drasticamente os impactos aerodinâmicos, mostrando-se uma solução altamente viável e segura para áreas de risco, requerendo apenas dimensionamento adequado de fundações para resistir às forças de sucção vertical.

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PALAVRAS-CHAVE: Abrigos Temporários. Aerodinâmica. Túnel de Vento. Domo Geodésico. Desastres Naturais.

RESUMEN
La pérdida de viviendas por desastres naturales expone a poblaciones vulnerables a condiciones precarias, exigiendo el desarrollo de refugios temporales resistentes a eventos climáticos extremos. El objetivo de este trabajo es evaluar la resistencia estructural aerodinámica de un refugio temporal en forma de domo geodésico frente a vientos de alta intensidad, comparándolo con una estructura convencional en forma de contenedor. La metodología consistió en simulaciones de Dinámica de Fluidos Computacional (CFD) utilizando el software RWIND, simulando tres escenarios basados en la Escala de Beaufort: viento fuerte (11 m/s), tormenta (18 m/s) y huracán (33 m/s). Los resultados demostraron la superioridad del domo, que disipó el flujo de aire de manera continua y suave. Bajo vientos de 33 m/s, el domo registró una fuerza de arrastre horizontal (Fx) de solo 2,497 kN, mientras que el contenedor alcanzó unos críticos 4,599 kN, evidenciando una inestabilidad estructural severa de la geometría ortogonal. Se concluye que el domo geodésico reduce drásticamente los impactos aerodinámicos, mostrándose como una solución altamente viable y segura para áreas de riesgo, requiriendo solo un dimensionamiento adecuado de los cimientos para resistir las fuerzas de succión vertical.

PALABRAS CLAVE: *Refugios Temporales. Aerodinámica. Túnel de Viento. Domo Geodésico. Desastres Naturales.*

INTRODUCTION

The displacement of individuals due to natural disasters — such as torrential rains, seismic activities, extreme temperatures, and severe storms — precipitates the destabilization of family structures, economic systems, and human well-being on a global scale annually (KEIM, 2008). Consequently, engineering residential structures resilient to these specific conditions is imperative, given that such catastrophic events severely compromise both the physical and psychological integrity of affected populations (FOLHA DE S. PAULO, 2023).

According to Freitas et al. (2014), human vulnerability is inherently linked to concurrent social processes and environmental shifts, a phenomenon conceptually defined as socio-environmental vulnerability (ONU NEWS, 2020). This vulnerability emerges from the intersection of two primary factors: first, social processes driven by the precariousness of individual living standards, including deficiencies in employment, income, healthcare, and education; second, environmental modifications induced by ecological degradation, such as the deforestation of hillsides (ALEKSIĆ et al., 2016).

Amidst accelerating global catastrophes, the necessity for populations to mitigate exposure to regions characterized by high frequencies of hurricanes, tornadoes, and floods remains critical (HENRIQUES; LOPES, 2019). To safeguard human habitations against these escalating environmental crises, a viable strategy involves developing sustainable residential units and temporary shelters engineered to resist natural disasters while ensuring equitable access for society (FREITAS et al., 2014).

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Natural disasters and their subsequent ramifications generate urgent, emergency-level demands within society (HONG, 2017). Exceptional crises, including slope failures and urban flooding in densely populated areas, compel governments and private sectors to implement rigorous interventions to restore local societal order (KOBIYAMA et al., 2006). Furthermore, Spink (2014) estimates that the global population exposed to devastating flood risks will double, escalating from one billion in 2004 to two billion by 2050. Given these projections, a fundamental inquiry arises: is it feasible to engineer highly resilient, secure housing units capable of mitigating the impacts of the planet's diverse natural disasters?

To address this challenge, the primary objective of this study was to design a scaled structural prototype of a temporary shelter engineered to withstand natural disasters. This design was validated through a critical experimental phase, utilizing digital wind tunnel simulations with controlled kinematics within the RWIND software environment to systematically evaluate the structural resistance of the proposed model.

1. THEORETICAL FRAMEWORK

The development of emergency shelters necessitates a multidisciplinary framework integrating civil engineering, fluid dynamics, and disaster management (ANDERS, 2007; CARBONARI; LIBRELOTTO, 2017). Because human vulnerability stems concurrently from anthropogenic social processes and environmental transformations, there is an urgent demand for habitability solutions capable of providing verifiable structural security (RESENDE et al., 2022).

To systematically evaluate the structural integrity of built environments subjected to wind-induced stress, Computational Fluid Dynamics (CFD) has emerged as an indispensable computational tool (ZAWAWI et al., 2018). CFD simulations enable both the precise characterization of microclimate wind flows and the automated derivation of wind loads acting upon geometrically complex structures (NÚÑEZ; SOUZA; ROCHA, 2012). Consequently, aerodynamic design methodologies utilize digital wind tunnels to analyze critical aerodynamic variables—including surface pressure distributions, velocity vectors, and flow streamlines—to accurately predict the magnitude of drag forces, which induce horizontal displacement, and lift forces, which cause vertical displacement, acting on the building envelope (MONTENEGRO; MENDOZA; FIGUEROA, 2026).

2. METHODOLOGY

The primary objective of this study was to develop a scaled structural prototype of a temporary shelter utilizing specialized physical modeling materials to alleviate the vulnerabilities of populations displaced by natural disasters. Structurally engineered within a computer-aided design (CAD)

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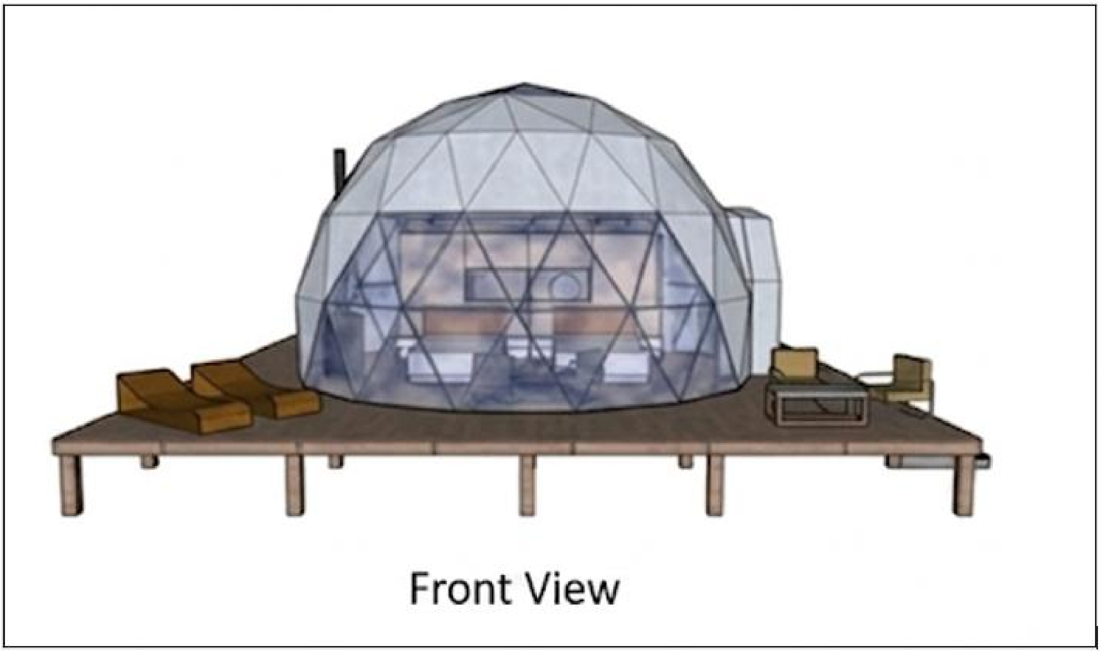
environment, the project features a geodesic dome designed to accommodate up to four occupants. The interior configuration encompasses four individual beds, an optimized bathroom, a fully equipped kitchen, and an integrated living area. This layout was systematically devised based on ergonomic principles and spatial fluidity to maximize internal circulation and fulfill essential habitability criteria (Figure 1).

Figure 1. Geodesic dome modeling in SketchUp



Source: Elaborated by the author.

Following the conceptual design phase, digital wind tunnel simulations were executed via RWIND software to rigorously evaluate the aerodynamic resistance and structural performance of the proposed geodesic configuration. A modular panel assembly methodology based on a 3V frequency structural scheme was adopted to construct the geodesic dome model. The structural design utilized three distinct types of linear components, designated as struts A, B, and C. Each typology featured specific lengths and angled end-cuts to guarantee accurate coupling at the joint nodes.

Based on the geometric parameters, the elements were standardized as follows: strut A (3.49 cm, 80.00° cuts), strut B (4.04 cm, 78.30° angles), and strut C (4.12 cm, 78.00° angles). To optimize the fabrication process, manufacturing was divided into the pre-assembly of two types of planar triangular faces. First, 45 'X'-type panels were constructed as isosceles triangles using two C struts for the sides and one B strut for the base. Concurrently, 30 'Y'-type panels were fabricated, also forming isosceles triangles structured with two lateral A struts and one basal B strut. The definitive dome assembly involved the spatial integration of all 75 prefabricated panels. To establish the characteristic spherical curvature and ensure the proper closure of the self-supporting structure, adjacent faces were

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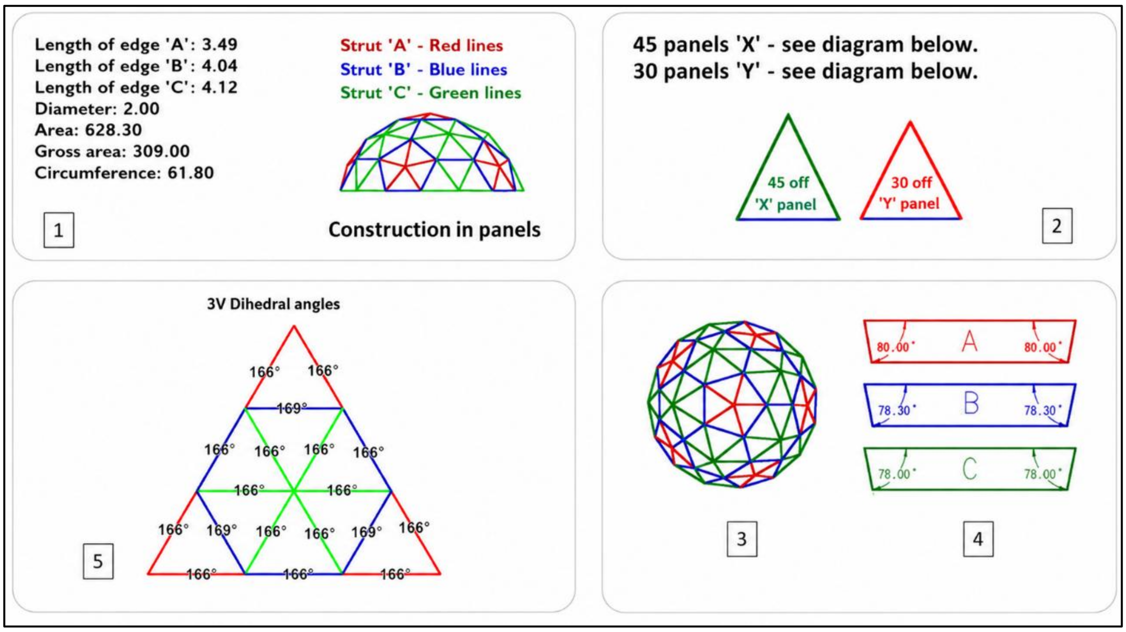
connected according to pre-established dihedral angles ranging from 166° to 169°, dictated by the nodal coordinates within the geodesic grid. Implementing this rigorous modulation resulted in a physical model with an explicit final diameter of 20.00 cm and a circumference of 61.80 cm (Figure 2).

Figure 2. Dome dimensions generated in GeoDome



Source: GeoDome.

2.1. Air Resistance Tests using RWIND software

A simulation approach utilizing Computational Fluid Dynamics (CFD) was used to simulate wind behavior around any building geometry (NÚÑEZ; SOUZA; ROCHA, 2012). This research is characterized as exploratory and experimental, employing the hypothetico-deductive method via computational fluid dynamics (CFD) simulation. To analyze the airflow dynamics, RWIND software (Dlubal Software – Demo version) was utilized as a digital wind tunnel. The computational domain applied to the control volume was dimensioned to ensure flow stabilization, *measuring 40.30 m in length, 20.15 m in width, and 12.98 m in height.* Two distinct solid structures were modeled and subjected to comparative evaluation: a geodesic dome (temporary shelter) and a parallelepiped structure (standard container) (Figure 3).

To ensure high aerodynamic fidelity and meet strict boundary conditions, the computational domain was discretized using a robust 3D *volumetric mesh comprising 199,872 cells and 237,874 nodes*. The aerodynamic parameters utilized the *RANS (Reynolds-Averaged Navier-Stokes) turbulence equations (equation 1)*. Two solid structures were modeled and subjected to comparative tests: a Geodesic Dome (shelter) and a parallelepiped building (Container) (Figure 3).

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$$\rho \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = \rho \bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \rho \overline{u_i' u_j'}\right] \quad (1)$$

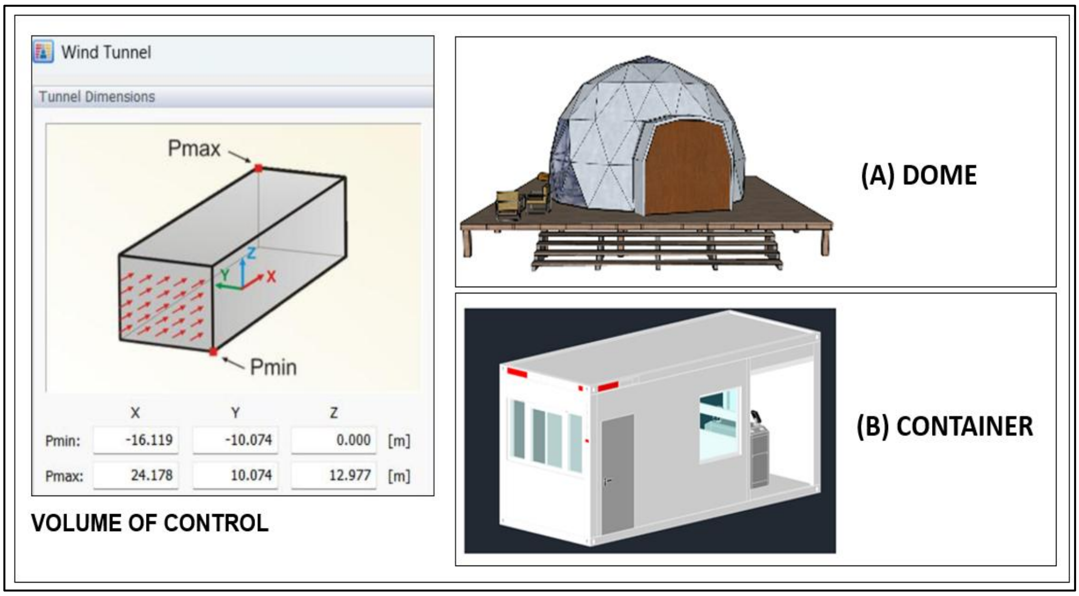
Three tests were performed to evaluate the airflow over two solid structures: (1) Dome; (2) Container. The first test was performed under strong wind conditions, with an average velocity of approximately 11 m/s. The second test was conducted under storm conditions, with an average velocity ranging between 17.2 and 28.3 m/s. The third test was performed under extreme hurricane/typhoon conditions, with a wind velocity exceeding 32.5 m/s. At the end of the 3 tests, a reliable comparison between the two aforementioned forms of shelter houses was obtained.

Three simulation scenarios were executed to evaluate the aerodynamic response of both configurations under progressive wind loads based on the Beaufort Scale (0–12):

1. Strong Wind (Beaufort 6–7): Average velocity of 11 m/s.
2. Storm (Beaufort 8–10): Average velocity of 18 m/s.
3. Hurricane/Typhoon (Beaufort 11–12): Extreme wind velocity of 33 m/s.

For each test, data regarding maximum surface pressure, suction (negative pressure), horizontal drag force (Fx), and vertical lift force (Fz) were collected. Residual graphs were monitored to ensure mathematical reliability, targeting convergence below 0.001 for pressure and 0.0001 for velocity over 500 iterations.

Figure 3. Geodesic Dome (A) and Parallelepiped building (B)



Source: Elaborated by the author.

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3. RESULTS AND DISCUSSION

3.1. General results of the airflow tests

To ensure structural safety against turbulence, the dome underwent resistance simulations in the RWIND software. The model was inserted into a digital wind tunnel to validate its aerodynamic behavior against varied airflows. As mentioned in the methodology, 3 tests were performed to evaluate the airflow over two solid structures: (1) Dome; (2) Container. Therefore, 3 tests were performed for the Dome and another 3 tests for the container, according to Table 1.

The first test performed with the dome was executed under strong wind conditions, with an average velocity of approximately 11 m/s, corresponding to the Beaufort Scale 6–7 range. This step allowed evaluating the initial behavior of the structure under significant aerodynamic stresses, yet compatible with common situations in intense but non-extreme weather events (Figure 4 – Experiment 1).

The second dome test was conducted under gale to storm conditions, with wind speeds ranging between 17.2 and 28.3 m/s (Beaufort scales 8–10). This test evaluated the structural performance during severe weather events, where elevated aerodynamic demands necessitate enhanced resistance from both the roof and ground supports. This scenario is critical for validating the stability and safety of the dome under extreme stress (Figure 4 – Experiment 2).

Table 1. Wind conditions and geodesic dome performance.

Wind Condition (Beaufort Scale)	Wind Speed (m/s)	Geodesic Dome Performance	Parallelepiped Performance
Strong / Very Strong (6–7)	10.8–16.9	Good stability, stresses well-distributed	Greater wind impact on flat surfaces, moderate instability
Gale / Storm (8–10)	17.2–28.3	Satisfactory resistance, no critical failures	Tendency for concentrated loads, risk of failures in lateral walls
Hurricane / Typhoon (11–12)	>32.5	Structure maintains performance superior to the parallelepiped, but with high stress on the supports	High structural vulnerability, great probability of collapse

Source: the standard speeds were taken from CEMTEC/MS.

The third dome test was executed under extreme hurricane/typhoon conditions, featuring wind velocities exceeding 32.5 m/s, which corresponds to Beaufort scales 11–12. This stage aimed to verify the maximum resilience of the structure against high-magnitude aerodynamic stresses characteristic of natural disasters. The results demonstrated that while the dome exhibits superior structural

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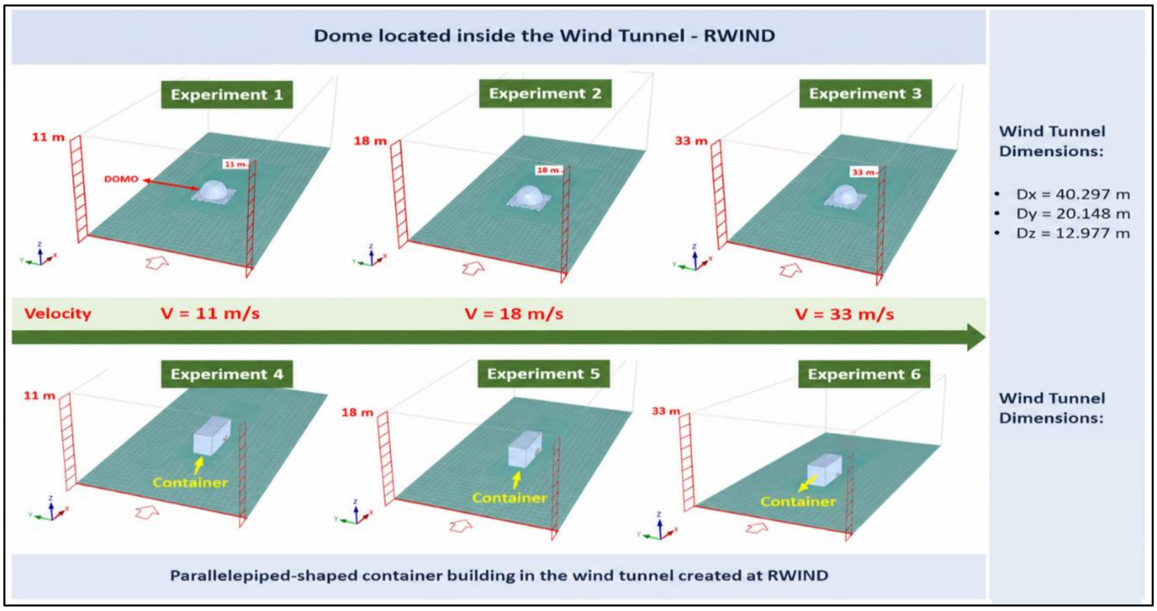
performance compared to the parallelepiped model, the base supports are subjected to critical stresses, underscoring the necessity for additional reinforcement under extreme wind conditions (Figure 4 – Experiment 3).

The fourth test was performed on the container under strong wind conditions, with an average velocity of approximately 11 m/s (Beaufort scales 6–7). In this scenario, the parallelepiped-shaped structure exhibited moderate instability, as its flat surfaces were directly exposed to wind action, resulting in a higher aerodynamic impact and concentrated structural stress. Although no immediate failure occurred, the observed performance was inferior to that of the dome-shaped model, indicating greater structural vulnerability even under non-extreme conditions (Figure 4 – Experiment 4).

The fifth container test was conducted under storm to severe gale conditions, with average velocities ranging between 17.2 and 28.3 m/s (Beaufort scales 8–10). Under these conditions, the parallelepiped-shaped structure exhibited unsatisfactory structural performance due to the direct incidence of wind on its flat surfaces, which induced stress concentrations on the sidewalls and significantly increased the demands on the roof (Figure 4 – Experiment 5). This behavior evidences a higher susceptibility to local failures and a loss of global stability relative to the dome-shaped model.

The sixth container test was executed under extreme hurricane/typhoon conditions, with wind velocities exceeding 32.5 m/s (Beaufort scales 11–12). This scenario aimed to evaluate the structural behavior of the parallelepiped-shaped structure, characterized by flat surfaces directly exposed to wind action. The results revealed high structural vulnerability, with severe stress concentrations occurring on the sidewalls and the roof. This culminated in significant global instability of the building and a high probability of collapse under extreme wind conditions (Figure 4 – Experiment 6).

Figure 4. Dome and container in the wind tunnel created in RWIND



Source: Elaborated by the author.

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3.2. Aerodynamic analysis of the dome

Figure 5 illustrates the three aerodynamic flow tests conducted on the dome, comprising an evaluative analysis of surface air pressure (top panel) and velocity vectors (bottom panel). The computational fluid dynamics (CFD) methodologies and validation parameters applied herein strictly align with recent literature, combining the fundamental protocols of Zawawi et al. (2018) with the validations by Montenegro et al. (2026). The inclusion of these references guarantees the authenticity, scientific traceability, and contemporaneity of the observed aerodynamic coefficients, confirming that the curved geometries of geodesic domes drastically reduce drag and flow separation compared to orthogonal shapes.

In Figure 5 (Item A), the pressure profile demonstrates that the frontal zone (indicated in red) experiences the direct impact of the 11 m/s wind, resulting in a positive pressure of approximately 76.5 Pa. Along the lateral and upper surfaces, the curvature of the dome accelerates the fluid, generating a negative pressure suction (indicated in blue) that induces a vertical lift force of approximately 0.804 kN. This behavior is characteristic of aerodynamic structures, where the upper vacuum constitutes the primary stress that the foundation must counteract.

Figure 5 (Item B) displays the surface pressure map of the dome under a wind velocity of 18 m/s. The frontal face (in red) remains the most affected area, withstanding a positive pressure of up to 205 Pa, whereas the remainder of the dome exhibits negative suction pressures reaching -340 Pa. This distribution yields a vertical force (Fz) of 2.158 kN, demonstrating that even under higher wind speeds, the lift force exceeds the horizontal drag force (Fx) of 0.742 kN.

Figure 5 (Item C) details the most critical scenario of this study, simulating hurricane-force winds at 33 m/s. The positive pressure on the frontal face peaks at 689.6 Pa, while the suction zone at the top and sides reaches -1144.6 Pa, resulting in a vertical lift force (Fz) of 7.265 kN. Although the horizontal drag (Fx) rises to 2.497 kN, the vertical force remains the predominant structural stress that the foundations must withstand.

In Figure 5 (Items D, E, and F), the velocity vectors—represented by arrows indicating directional orientation—show that the air stream rises and accelerates as it contours the curvature of the structure, reaching its maximum intensity at the apex. Correspondingly, the streamlines reveal that the wind maintains an organized flow across the frontal face but generates turbulence and wake zones downwind of the dome. Collectively, these panels demonstrate that the spherical geometry facilitates fluid passage, despite causing flow compression at the apex and an aerodynamic disturbance immediately behind the structure. The color gradation of the vectors indicates that the air accelerates significantly upon reaching the top of the dome, whereas zones near the base and the platform exhibit reduced velocities due to friction and direct obstruction.

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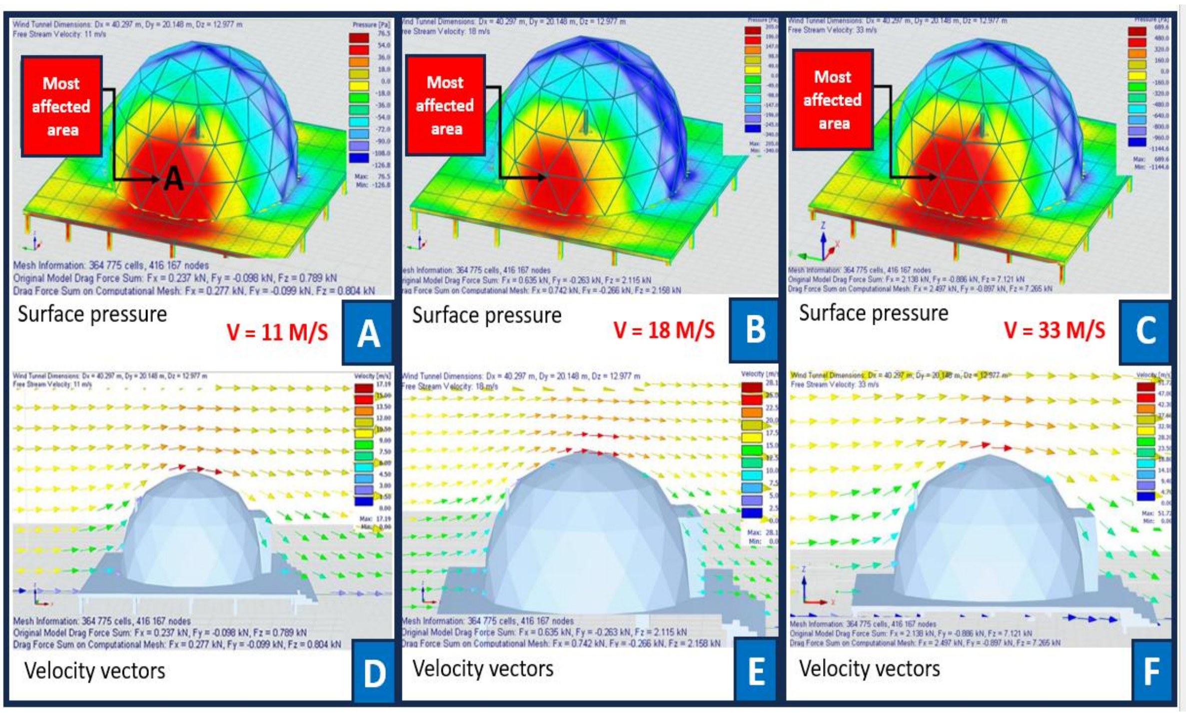
Figure 5. Surface pressure graphs and velocity vectors for the Dome



Source: Elaborated by the author.

3.3. Aerodynamic analysis of the container

Figure 6 (Item A) presents the container test under an 11 m/s wind, revealing a structural behavior distinct from that of the dome. The flat frontal face generates a positive pressure of 79.5 Pa; however, the critical parameter is the horizontal drag force (Fx), which reaches 0.511 kN due to the low aerodynamic efficiency of the cubic geometry. The vertical lift force (Fz) is also elevated, reaching 0.401 kN, indicating that flat surfaces experience significantly greater stresses under identical meteorological conditions.

Figure 6 (Item B) details the container test under an 18 m/s wind, evidencing a critical structural response attributable to its orthogonal geometry. The frontal pressure reaches 212.8 Pa, while the horizontal drag (Fx) increases to 1.368 kN and the vertical lift (Fz) reaches 1.074 kN. Compared to the dome under the same velocity (Fx of 0.742 kN), the container experiences substantially higher stresses, demonstrating pronounced aerodynamic vulnerability. Additionally, it exhibits a more intensive internal air circulation and a visibly more unstable leeward recirculation zone.

Figure 6 (Item C) represents the most extreme scenario for the container, simulating hurricane-force winds at 33 m/s. The pressure on the flat frontal face reaches 715.4 Pa, while the horizontal drag force (Fx) rises to a critical value of 4.599 kN, illustrating the substantial aerodynamic resistance

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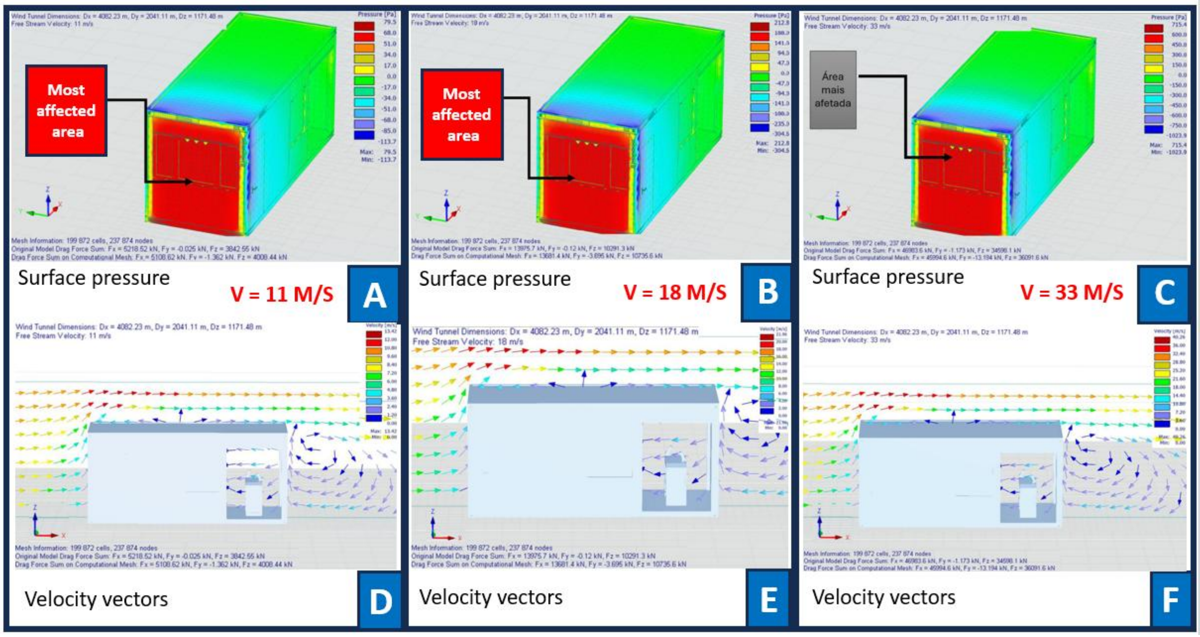
imposed by this geometry. Simultaneously, the lift force (Fz) increases to 3.609 kN, indicating that the total overturning and thrust stresses are massive compared to those observed in the aerodynamic model. Furthermore, the velocity vectors in Figure 6 indicate that the air stream is forced to rise abruptly along the frontal face, generating critical velocities over the roof, while the internal flow through the opening becomes highly accelerated.

Figure 6. Surface pressure graphs and velocity vectors for the Container



Source: Elaborated by the author.

The comparative aerodynamic behavior of the two structures reveals substantial disparities in structural efficiency. Table 2 summarizes the dynamic forces extracted from the RWIND simulations. Figure 7 serves as a consolidated compilation of all flow tests, positioned adjacently to facilitate a direct aerodynamic comparison. Across all three velocity conditions (11, 18, and 33 m/s), the airflow is observed to contour the dome continuously and fluidly, thereby minimizing structural impacts. Conversely, the container abruptly obstructs the windward flow, generating intense turbulence zones and large vortices in its leeward wake. This comprehensive panel visually demonstrates the underlying mechanism by which the orthogonal geometry induces significantly higher drag and lift forces relative to the curved configuration.

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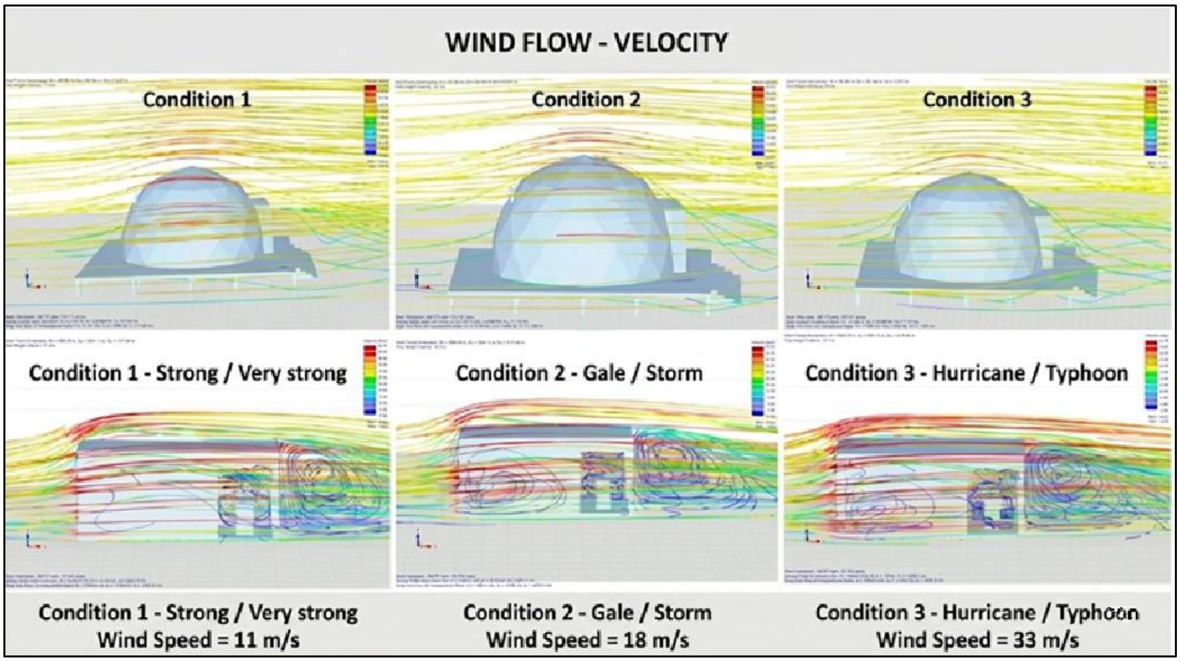
Table 2. Comparative summary between Dome and Container.

Wind Condition	Structure	Max. Pressure (Pa)	Min. Pressure – Suction (Pa)	Drag Force – Fx (kN)	Lift Force – Fz (kN)
Moderate Wind (11 m/s)	Dome	76.5	-126.8	0.277	0.804
	Container	79.5	-113.7	0.511	0.401
Storm (18 m/s)	Dome	205	-340	0.742	2.158
	Container	212.8	-304.5	1.368	1.074
Hurricane (33 m/s)	Dome	689.6	-1,144.6	2.497	7.265
	Container	715.4	-1,023.9	4.599	3.609

Source: Elaborated by the author.

Figure 7. Collection of flow tests in the RWIND software



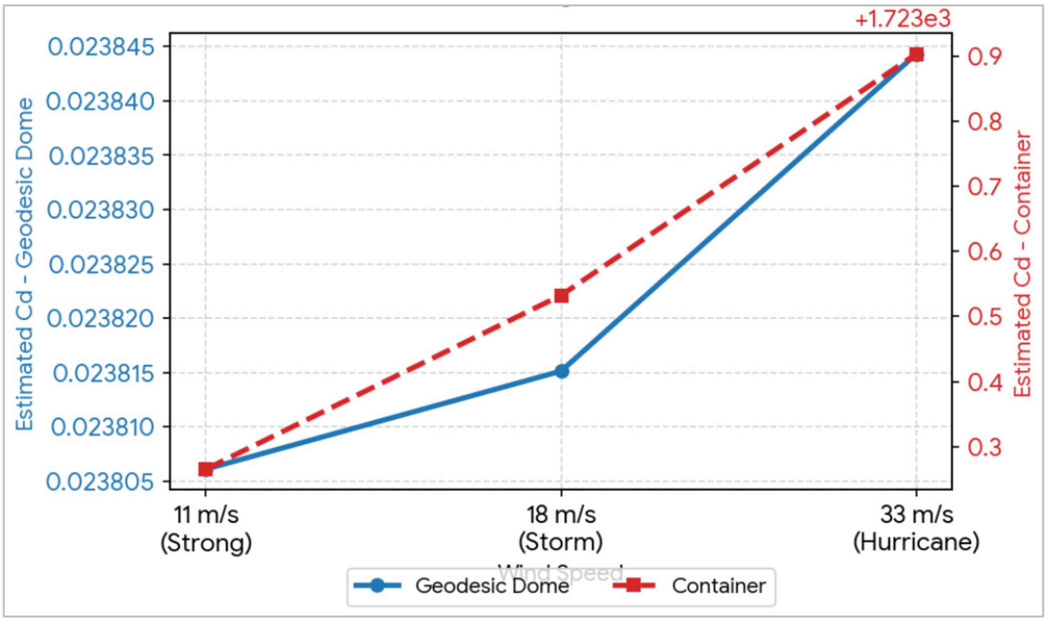
Source: Generated by the author using RWIND software.

Finally, the aerodynamic performance of the shelter could be further elevated by incorporating wind shear structures and debris deflectors. Recent aerodynamic studies, such as the classical wind loading research by Holmes (2015), demonstrate that implementing physical deflectors and shear structures significantly reduces the impact of flying debris and high-velocity wind streams during severe storms. Comparing our baseline CFD results with these structural mitigation techniques, it is evident that while the geodesic dome naturally dissipates continuous airflow, the addition of external deflectors would prevent localized puncture damages from wind shear, thereby maximizing the shelter's survivability in extreme hazard zones.

An estimate of the projected frontal area was made for the two structural models studied. For the dome, the calculated area was approximately 157 m^2 and for the container, approximately 40 m^2. This allowed for a comparison between the drag coefficients applied to the two structures (Figure 8).

As can be seen in the behavior of the curves in Figure 8, the shape of the container generates massive turbulence that saturates and maintains critical drag at any speed range, operating at orders of magnitude completely disproportionate to those of the spherical dome. It is noted that the drag coefficient of the Dome is lower than that of the Container.

Figure 8. Estimation of Drag Coefficient (Cd)



Source: Elaborated by the authors.

4. FINAL CONSIDERATIONS

The present study successfully demonstrated the technical viability and high resilience of temporary shelters designed as geodesic domes for natural disaster scenarios. Computational fluid

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dynamics (CFD) simulations, performed in a digital wind tunnel across three distinct Beaufort scale conditions (up to extreme hurricane-force winds of 33 m/s), proved the aerodynamic superiority of the spherical geometry compared to traditional parallelepiped containers. By continuously and fluidly contouring the windward flow, the dome drastically reduces horizontal drag forces (Fx), maintaining global stability under conditions where standard orthogonal containers exhibited pronounced vulnerability to massive drag, turbulent wakes, and imminent structural collapse.

However, this study also highlights a critical structural factor for the real-world implementation of domes: the significant generation of lift force (suction, (Fz) at the apex of the structure due to localized airflow acceleration. To address this phenomenon, future engineering efforts must focus on developing advanced anchoring and foundation systems capable of withstanding severe vertical overturning and uprooting stresses.

Regarding methodological limitations, the exclusive reliance on numerical CFD simulations rather than physical experimental validation was necessitated by institutional and financial constraints. The host university lacked an operational wind tunnel facility, and the construction of a proprietary apparatus was unviable. Furthermore, establishing external collaborative partnerships to conduct physical testing was logistically unavailable and cost-prohibitive for the research team.

A highly pertinent international study addressing the dynamic behavior and wind resistance of domes, specifically examining the vibration frequencies of the subject structure, was conducted by Radoń et al. (2026). Conversely, the study by Li et al. (2023) validates computational fluid dynamics (CFD) data using physical wind tunnel testing, meticulously detailing how streamlines converge at the dome apex to generate suction forces (lift/drag), thereby demonstrating how curved geometries significantly reduce pressure concentrations relative to orthogonal shapes. However, the investigation presented in this paper, which evaluates wind action on both a geodesic dome and a container, did not assess the vibrational frequencies of these structures, focusing exclusively on aerodynamic forces and drag coefficients. A frequency-based vibration analysis would necessitate a more comprehensive structural investigation, whereas the primary objective of this study was to implement the RWIND software framework across the two proposed geometries.

As an extension of this research, future work should be directed toward three main guidelines: 1) the execution of in-depth structural simulations and physical testing to detail the calculation of foundation and anchorage systems; 2) the investigation of sustainable, renewable, and low-cost structural materials, such as bamboo, to mitigate the environmental footprint of the shelters; and 3) the development of foldable and retractable modular concepts based on geometric folding principles (origami) to optimize transport logistics, reduce storage volume, and accelerate deployment in emergency zones. Ultimately, the proposed model offers a robust contribution to civil engineering, providing a safer and more resilient housing alternative to mitigate socio-environmental vulnerability.

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