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Numerical Simulation of the Strength of an Agricultural Greenhouse Structure

Konan Eric Konan[1], Aka Stéphane Koffi[2], Zokagon Aristide Tieu[3]

[1,2]*Technology Laboratory, Training and Research Unit in the Sciences of Matter Structures and Technology, Félix Houphouët-Boigny University, Abidjan, Côte d'Ivoire*

[3]*Fundamental and Applied Physics Laboratory, Training and Research Unit in Fundamental and Applied Sciences, Nangui Abrogoua University, Abidjan, Côte d'Ivoire*

Abstract: Our study is a static analysis of the strength of an agricultural greenhouse structure. The greenhouse of 500 m² (20 m x 25 m) has a double-arched roof with vertical and horizontal spans. The eaves height of 2.5 m is half the ridge height. It is composed of galvanized steel tubes and covered with a polyethylene film. The simulation was performed using SOLIDWORKS software for loads in a tropical environment. The maximum wind speed used was 33.4 m/s and the installation forces were 70 Pa. This study shows that the structural components generally have low equivalent Von Mises stresses, around half the material's yield strength (203.9 MPa).

The maximum value of this stress, 196 MPa, is observed near the connections of some spans. These spans are not load-bearing and can be reinforced. Thus, we have a minimum factor of safety (FOSmin) of 1.04, indicating optimal strength for local operating conditions.

The spans also experience the greatest equivalent displacements (Umax = 62.99 mm), as well as equivalent strains, the maximum value of which is 842.8 micro. Buckling analysis gives a load factor of 13.921 and a maximum resulting amplitude of 59.16 milli. Therefore, this structure exhibits good strength under the aforementioned loads. In addition to the tropical adaptation of the conceptual approach to international standards, this study illustrates the structural strength of a greenhouse whose covered areas can be easily adapted.

Keywords: Simulation, greenhouse, structure, stress, strain.

I. INTRODUCTION

This Agriculture remains an important lever in tropical environments (Larouche-Tremblay et al., 2025), particularly in Africa (Jacquemot, 2023) and especially in Côte d'Ivoire, where it forms the core of the economy (Ouguehi et al., 2025). Adopting or adapting agricultural production optimization techniques remains a constant challenge in our climate. (Rivier, 2017). The use of greenhouses in this environment is one way to address this challenge. The structure of these greenhouses is important for their resistance to harsh weather conditions. Standards for conceptual approaches exist in China, which has the largest number of greenhouses, as well as in Europe, the United States, and elsewhere.

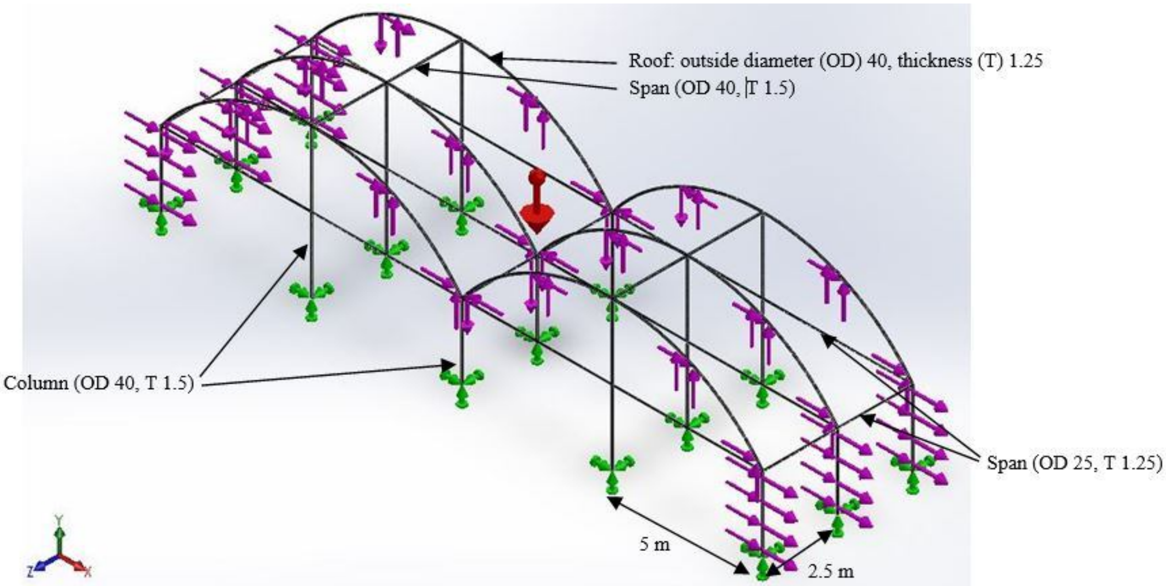
Our study focuses on the static analysis of a greenhouse structure in a tropical environment. In addition to gravity (the structure's own weight), the polyethylene roofing, the actions of the equipment, and wind constitute the loads considered in this study.

First, we describe the material and methodological approach to contextualizing the aforementioned standards. Then we analyse the results obtained before concluding.

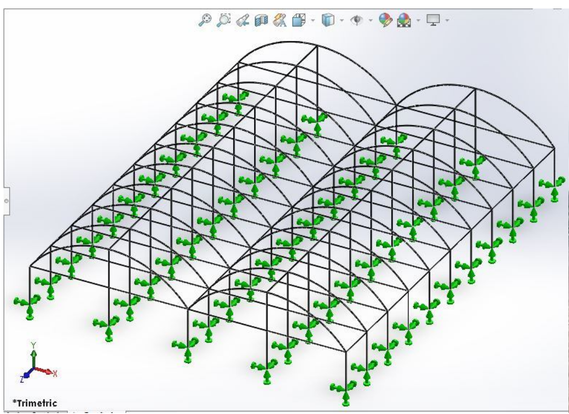
II. MATERIALS AND METHODS

A. Greenhouse structure

Figure 1 presents several greenhouse configurations: a diagram of the simplified model (20 m x 5 m) of the greenhouse, another one the complete greenhouse (20 m x 25 m), and a model of a real-world greenhouse. This simplification is reliable and optimal for calculations (Dong et al., 2025; Fernández-García et al., 2020; Wang et al., 2023). Welds of 27.78 mm connect the different components of the structure.



1.a. Simplified loaded model



1.b. Complete greenhouse on supports

1.c. Real case (Serre Ivoire, 2026)

Fig. 1 Greenhouse configuration

The main characteristics of the greenhouse are given in table I.

TABLE I
MAIN FEATURE OF THE GREENHOUSE

Designation	**Values**
Width	20 m
Length	25 m
Ridge height	5 m
Eaves height	2.5 m
Surface area (structure)	164.81 m²
Volume (structure)	0.11 m3
Mass (structure)	110.31 kg
Weld masses (structure)	10.80 kg

B. Modeling

The greenhouse model was generated using SOLIWORKS 2023 software (Dassault Systèmes, 2023). The static analysis performed on the simplified model was conducted using a coarse mesh. This mesh was refined on a few elements. The constitutive law is linear elasticity (Hooke) in an isotropic environment. The mechanical properties of the material are shown in table II.

TABLE II
MAIN FEATURE OF THE GREENHOUSE

Designation	**Values**
Yield strength σ_e	203.94 MPa
Tensile strength σ_r	356.9 MPa
Elastic modulus E	200 GPa
Coefficient de poisson ν	0.29
Density ρ	7,870 kg.m-3

C. Loads combination

The installation forces are estimated at 70 Pa in accordance with European (CEN, 2015) and Chinese (CPP, 2016) standards. The pressure exerted by the 0.2 mm polyethylene film is 2 Pa (Wang et al., 2023). This pressure is in the direction of gravity, as are the installation forces. The maximum wind speed considered is 33.4 m/s, and the air density at 30°C is 1.164 kg/m³. Therefore, the air pressure is:

$$P = 1/2\ 1.164 \times 33.4^2 = 649.2559 \text{ Pa; we use a value of } P = 650 \text{ Pa.}$$

The wind load on the first roof (on the left) takes into account American standards (NGMA, 2004). For the second roof, we relied on recent literature for this configuration (Kim et al., 2021; Qi et al., 2026; Wang et al., 2021). Figure 2 defines the loads combination.

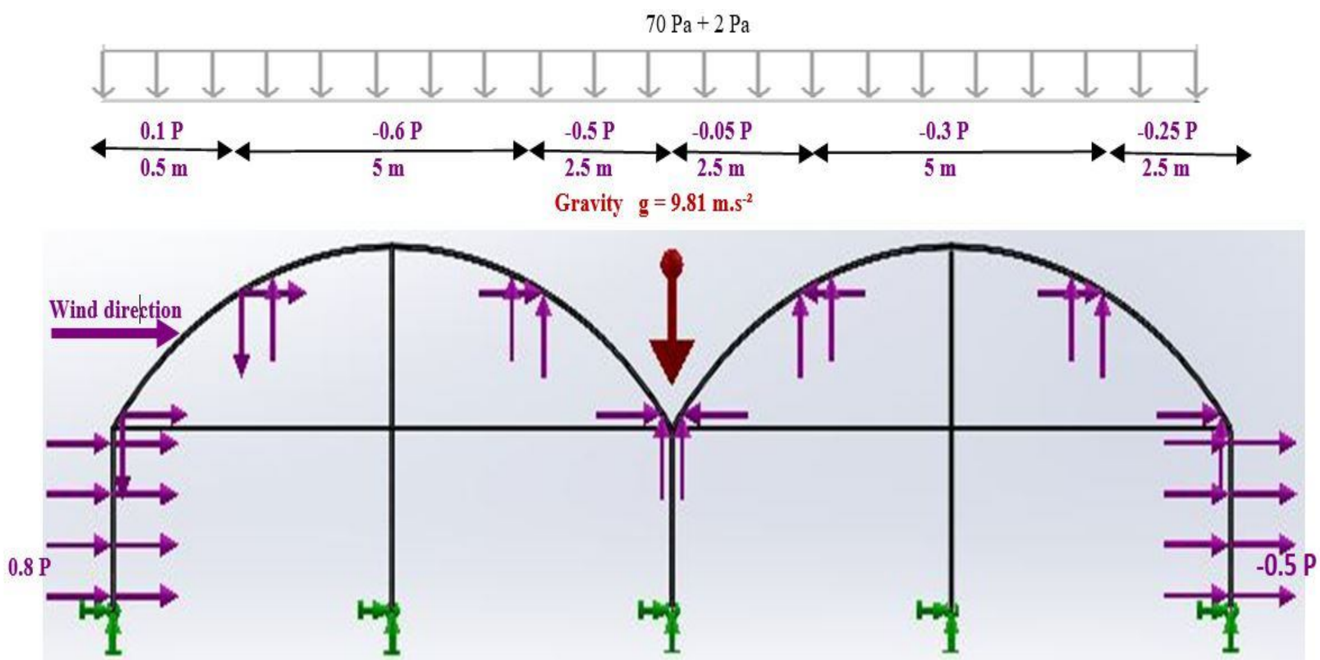


Fig. 2 Loads combination

III. RESULTS AND DISCUSSION

A. Static analysis

Figure 3 shows the proportions of the equivalent Von Mises stresses in the simulated simplified model. The deformation scale is 30 for clarity.

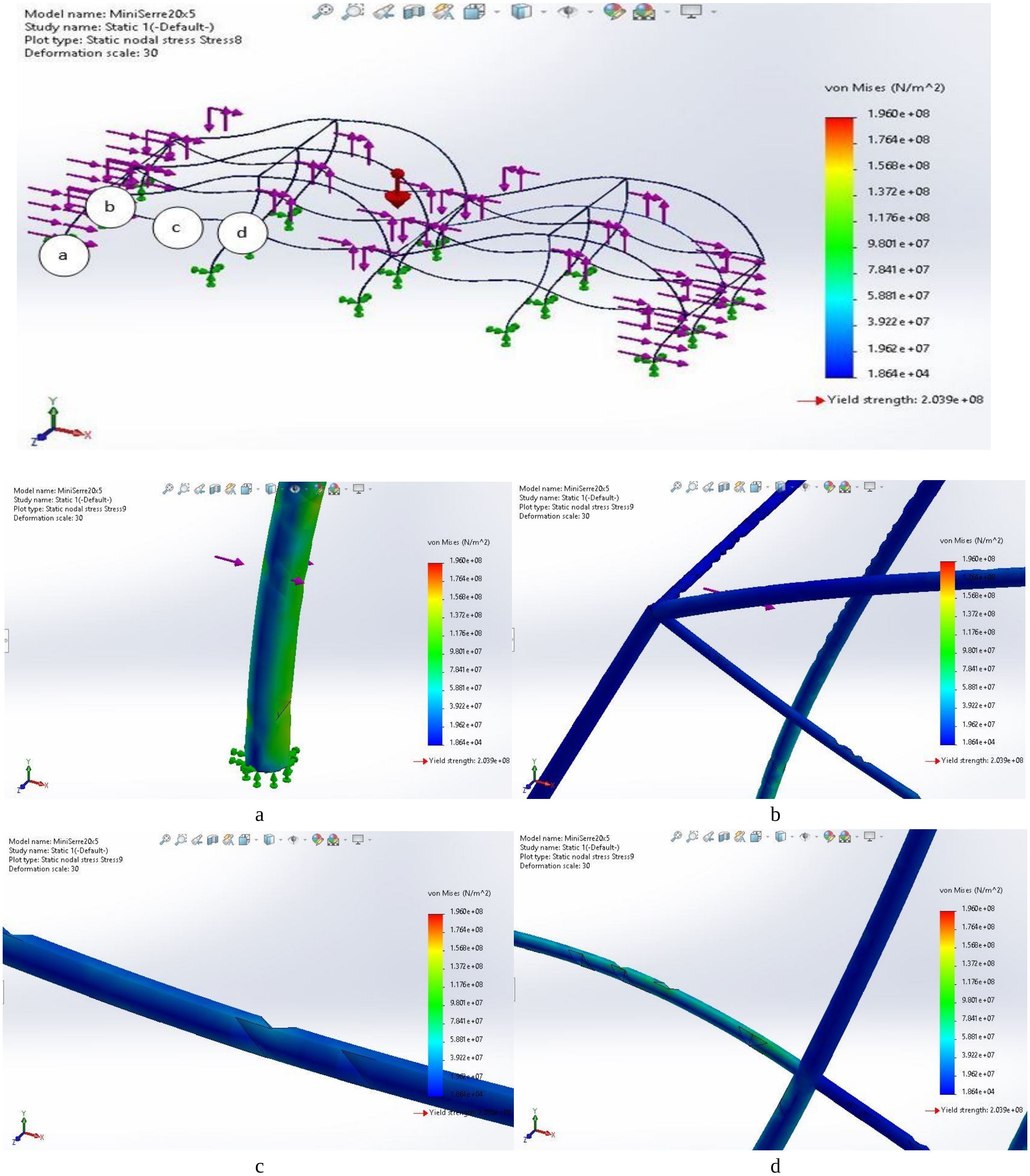


Fig. 3 Von Mises equivalent stress

The maximum observed Von Mises equivalent stress is 196 MPa, which gives us a minimum factor of safety:

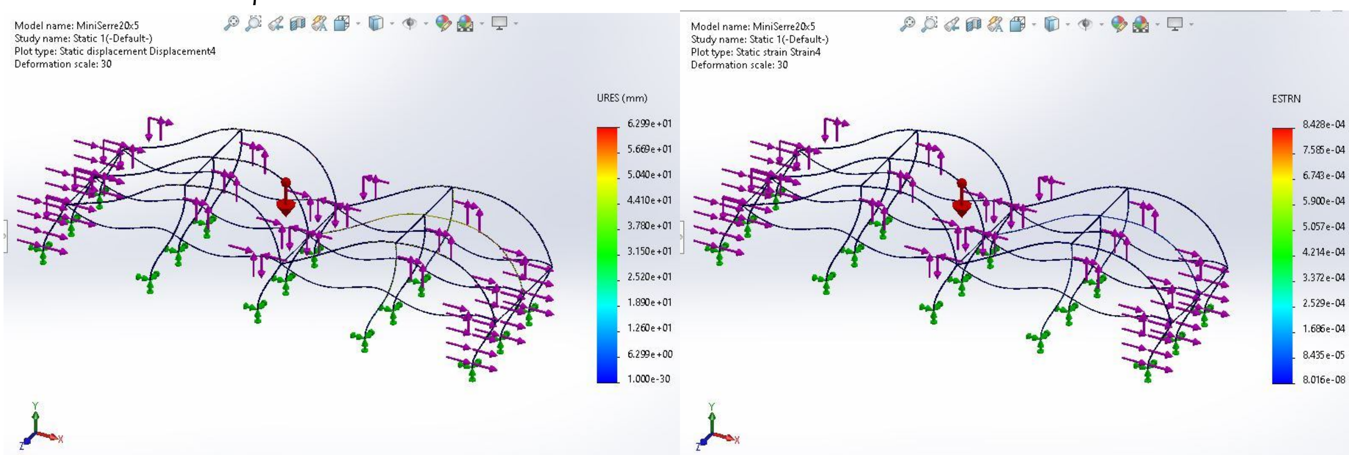
$$FOS_{min} : = \sigma_e / \sigma_{VMmax} = 203.9 / 196 \Rightarrow FOS_{min} = 1.04.$$

This factor of safety highlights a well-dimensioned structure under limit load conditions. Specifically, it indicates minimal material usage to ensure the structure's strength. The advantages of this simulation approach are:

- a structure that is not undersized, thus avoiding the risk of failure under extreme operating conditions;
- a structure that is not oversized, therefore requiring minimal materials and installation (assembly);
- identification of areas susceptible to structural failure for potential reinforcement;
- minimal shading of the structure to promote crop growth (Emekl et al., 2010; Maraveas et al., 2020; Saltuk, 2019);
- Flexibility in defining the structure's components to accommodate varying load conditions;
- etc.

By observing the structural components, this maximum value of the equivalent Von Mises stress is reached near the connections of certain non-load-bearing spans. All other components have stress values below half the material's yield strength.

This trend is also observed in the displacements (figure 4). The maximum equivalent displacement is 62.99 mm with a maximum equivalent strain of 842.8 µ.



4.a. Displacement 4.b. Strain

Fig. 4 Displacement and strain

B. Stability analysis

Given the slenderness of the structural components, a buckling simulation of the simplified model was performed. We obtained a load factor of 13.921 (figure 5) and a maximum resultant amplitude of 59.16 milli.

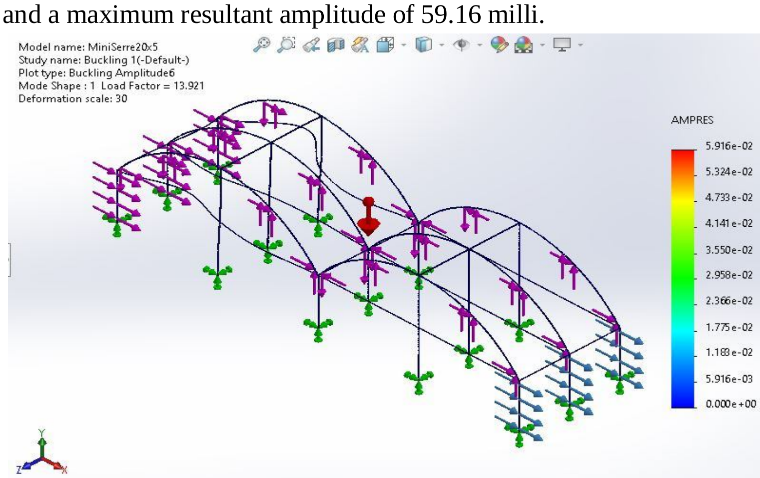


Fig. 5 Buckling

The static study is therefore sufficient to evaluate the strength of the greenhouse structure.

IV. CONCLUSIONS

Our study focused on the structural strength of a greenhouse in a tropical environment. With an arched roof and vertical or horizontal spans, the greenhouse frame is composed of galvanized steel tubular elements. The loading conditions took into account certain international standards and recent literature. Using SOLIDWOKS software, the static analysis gives equivalent Von Mises stress values around half the yield strength of 203.9 MPa. The maximum values of this stress, 196 MPa, observed on some spans did not significantly impact the structure's strength. The maximum resulting displacement of 62.99 mm and the maximum resulting deformation of 842.8 micro are acceptable for a structure with slender components. This structural strength was confirmed by the buckling analysis of the simplified section, which yielded a load factor of 13.921 and a maximum resulting deformation of 59.16 milli.

This study highlights the optimal structural strength of a greenhouse model. It indicates the components, particularly some spans for which the connections and operation must be carefully considered. Furthermore, the flexibility of the structural components and their generalizability to various covered areas can be readily implemented.

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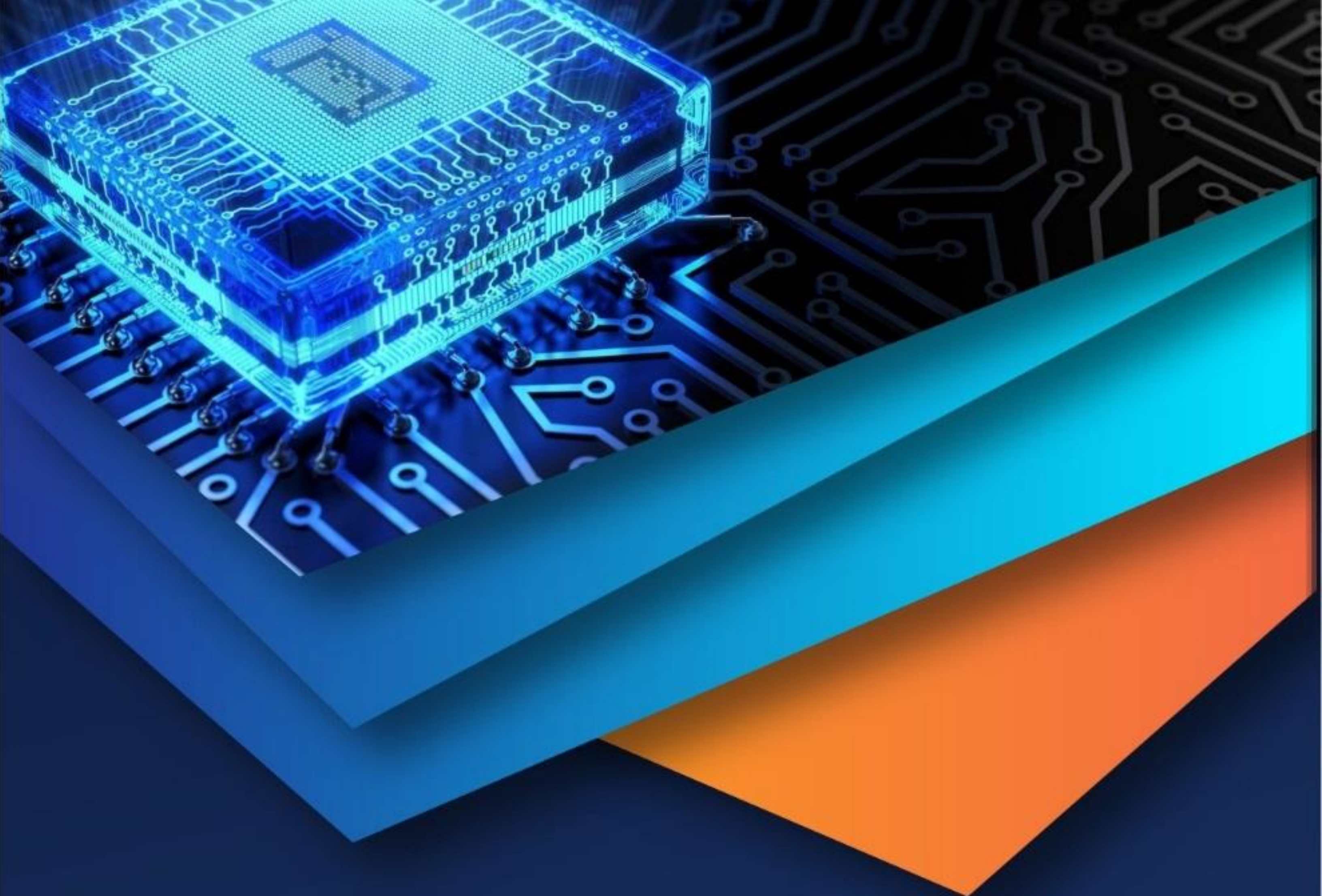

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