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A Review on a Case Study of Calculating Carbon Footprint and Cultivating Carbon Sinks in Educational Institute

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Abstract: The escalating concentration of greenhouse gases (GHGs) in Earth's atmosphere, driven by anthropogenic activities, poses a critical threat, leading to global warming and climate change. This review paper synthesizes current knowledge on the greenhouse effect and the quantification of emissions through carbon footprint assessment, with a particular emphasis on the building sector. Globally, buildings and construction contribute significantly, accounting for over 34% of energy demands and 37% of energy and process-related CO2 emissions in 2022, with a consistent growth trend. The paper outlines the GHG Protocol's classification of emissions into Scope 1 (direct), Scope 2 (indirect from purchased energy), and Scope 3 (other indirect), highlighting the complexities in measuring Scope 3 emissions. It discusses the pressing challenges of climate change and proposes a multifaceted approach for emission reduction, including transitioning to renewable energy, enhancing energy efficiency, electrifying transport, promoting afforestation, utilizing Carbon Capture and Storage (CCS) technologies, implementing sustainable agricultural practices, and enacting robust policies. The literature review delves into various methodologies for carbon footprint assessment in educational institutions, identifies key emission sources, and explores the potential of carbon sinks and offsets. Finally, it highlights critical research gaps, particularly regarding comprehensive Scope 3 emissions measurement and the integrated application of carbon sinks and offsets for sustainable built environments.

I. INTRODUCTION

The greenhouse effect, a natural phenomenon essential for maintaining Earth's habitable temperature, involves the trapping of heat near the planet's surface by substances known as greenhouse gases (GHGs). These gases primarily include carbon dioxide (CO2), methane (CH4), ozone (O3), nitrous oxide (N2O), chlorofluorocarbons (CFCs), and water vapor (H2O). While naturally occurring GHGs are vital for sustaining life on Earth, human activities have led to an unprecedented increase in their atmospheric concentrations, resulting in an abrupt rise in global temperatures, a phenomenon commonly referred to as Global Warming. This escalation in global temperature presents a pressing concern for the planet's sustainability.

To quantify and standardize these diverse GHG emissions, they are typically converted into a common unit, most often expressed in terms of carbon equivalent. The total amount thus calculated is termed the carbon footprint. While carbon emissions stem from various sectors, this review primarily focuses on the building sector's contribution to this global challenge.

According to the "Global Status Report for Buildings and Construction" (UNEP, COP27, Egypt), the building and construction sectors were responsible for over 34% of global energy demands and approximately 37% of energy and process-related CO2 emissions in 2022. This sector's emissions have consistently grown at an average rate of 1% per year since 2015. India, in particular, attributes 40% of its CO2 emissions to the building sector, with projections indicating a doubling of these emissions by 2050 in the absence of sustainable alternate methods and technologies. The 2022 Emissions Gap Report (UNEP) underscores the urgency, calling for a nearly 45% global emission reduction to avert the most severe impacts of climate change.

In line with these global efforts, the UNCCC (Climate Change Conference) (COP21) in Paris, France, on December 12, 2015, emphasized the critical need to restrict the global temperature increase to within 1.5∘C above pre-industrial levels. This target aims to reduce global carbon emissions by decreasing ambient temperatures, thereby lowering energy demand.

Carbon emissions from buildings are typically categorized under three scopes, as defined by the GHG Protocol, the world's most widely adopted standard for greenhouse gas accounting. A comprehensive understanding of these scope categories is crucial for achieving "NET ZERO" emissions:

1) Scope 1: Direct Emissions: These emissions originate from sources owned or directly controlled by an organization. In the context of an educational institute, this includes:

- Static Emissions: GHGs generated from stationary equipment through physical and chemical processes, such as the combustion of fossil fuels for food preparation in messes, cafeterias, or other food courts.
- Mobile Emissions: Direct emissions from institute-owned vehicles due to the combustion of diesel or petrol for the transportation of students, faculty, and staff.
- Fugitive Emissions: Unintended emissions resulting from the leakage of hydrocarbons from equipment like air conditioning and refrigeration systems. Calculating Scope 1 emissions is relatively straightforward, often by reviewing purchase records for gas cylinders, vehicle fuel, and similar direct energy consumption.

2) Scope 2: Indirect Emissions from Purchased Energy: These are indirect emissions generated from the purchase of electricity, heat, or steam that is used to operate various units such as lighting, coolers, fans, laser printers, and HVAC systems. Quantifying these emissions can be easily achieved by analyzing electricity utility bills over a specific period.

3) Scope 3: Other Indirect Emissions: These are also indirect emissions but are neither produced by the institute itself nor directly controlled by it. They are a consequence of the institute's operations, yet occur from sources not owned or controlled by the organization. A significant example in the educational sector is emissions from employees and students commuting using their personal vehicles. While Scope 1 and 2 emissions are relatively easy to calculate, Scope 3 emissions pose a considerable challenge due to the lack of precise data on individual commute patterns (vehicle type, mileage, condition, driving skill). Consequently, these emissions are often excluded from an institute's carbon footprint calculations or require laborious estimation. Scope 3 also includes emissions indirectly generated by the institution through the incineration and disposal of various types of solid waste.

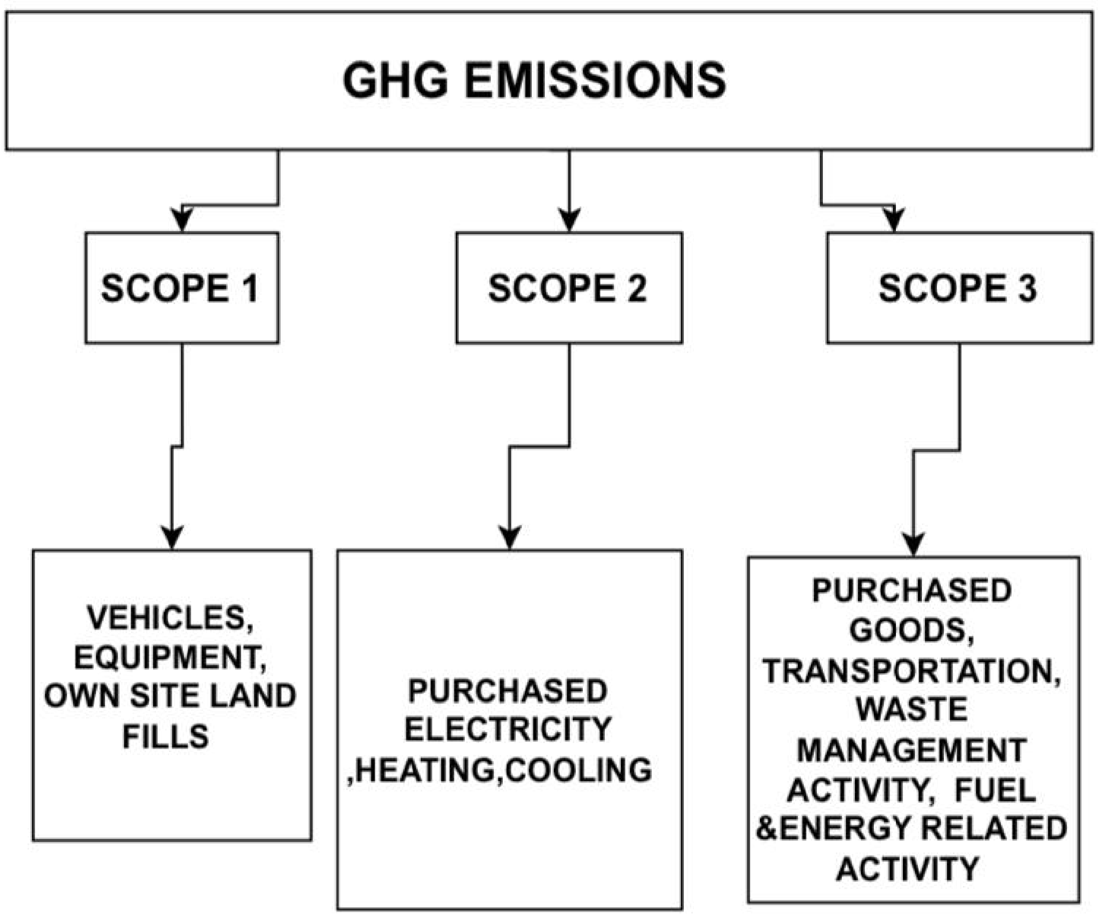

Figure 1 Various Scope Categories as Defined by GHG Protocol Standard Corporate

II. CHALLENGES OF THE PRESENT ERA

Greenhouse gas emissions pose significant challenges, primarily manifesting as climate change and its far-reaching effects on Earth and human society. While the natural greenhouse effect is necessary for life, the sharp rise in anthropogenic GHG emissions has created a global state of anxiety. To prevent the severe adverse effects of climate change and preserve a habitable planet, the Intergovernmental Panel on Climate Change (IPCC 2018) stresses that the global temperature must not increase by more than 1.5∘C over pre-industrial levels. Despite international pledges to combat climate change, global emission rates continue to climb, with the current warming already reaching 1.1∘C. Projections indicate that swift action to cut GHG emissions could still limit warming to 1.5∘C by 2050; otherwise, the global temperature could surge to 3∘C by 2100 (IPCC). The consequences are already evident, with recent events like widespread floods and Australian forest fires serving as stark reminders of climate change's impacts.

Reducing global GHG emissions is paramount for the planet's long-term sustainability, ensuring the safety of current and future generations, and preserving Earth's bionetwork and biodiversity. Encouragingly, increased awareness regarding sustainable development has led to positive responses in emission reduction scenarios.

III. THE WAY AHEAD

Reducing carbon emissions and the overall carbon footprint is crucial for planetary sustainability. Numerous strategies can facilitate progress in this direction:

1) Transition to Renewable Energy Sources: A significant reduction in carbon emissions from power generation and other sectors can be achieved by phasing out fossil fuels and vastly increasing the deployment of renewable energy sources such as hydro, solar, geothermal, wind, and bioenergy. India's commitment is evident, with its renewable energy capacity expanding by 165% in a decade, from 76.38 GW in 2014 to 203.1 GW in 2024, as reported by the Ministry of New and Renewable Energy.
2) Energy Efficiency Measures: Improving energy efficiency across various sectors, including buildings, transportation, industries, and appliances, can substantially reduce energy consumption, leading to lower carbon emissions while also yielding cost savings. The International Energy Agency (IEA) highlights that energy efficiency measures implemented between 2000 and 2018 contributed to a 12% reduction in global energy-related CO2 emissions.
3) Electrification of Transport Sector: The transition from traditional internal combustion (IC) engine vehicles to electric vehicles (EVs) has demonstrated a significant decrease in emissions from the transportation sector, a major contributor to carbon emissions under GHG Protocol scopes 1 and 3. The IEA reported 14 million EVs worldwide in 2023, indicating a more than 20% annual increase in EV adoption.
4) Afforestation and Reforestation: Trees serve as potent carbon sinks due to their high capacity for sequestering carbon dioxide. While the world's forest area decreased by 178 million hectares between 1990 and 2020 (Food and Agriculture Organization (FAO) report), many nations are advancing forestry initiatives. Increasing forest cover through reforestation (restoring degraded forests) and afforestation (planting trees in previously unforested regions) can significantly enhance carbon dioxide absorption from the atmosphere.
5) CCS (Carbon Capture and Storage) Technology: CCS is a vital climate mitigation technology that involves extracting carbon dioxide from large point sources (e.g., power plants, industrial facilities) or directly from the atmosphere, and then permanently storing it underground. The Global CCS Institute reports 41 major CCS facilities currently operating or under construction worldwide.
6) Sustainable Agriculture Practices: Agricultural carbon emissions represent 10–12% of total global emissions. Studies, such as one published in Nature Sustainability, suggest that sustainable agricultural methods could reduce global agriculture emissions by 50–90% by 2050. Implementing practices like soil carbon sequestration, agroforestry, organic farming, and precision farming can lower agricultural emissions while promoting food security.
7) Policy and Regulatory Measures: Governments play a pivotal role in reducing carbon emissions through the implementation of robust policies and regulatory measures. The Climate Action Tracker provides data on climate policies and their effectiveness across nations. Governments can encourage cleaner technologies, establish carbon pricing mechanisms, and personalize emission reduction targets to drive meaningful change.

In conclusion, the building sector, encompassing both construction and operational phases, holds a decisive role in reducing carbon emissions associated with the built environment, contributing significantly to a sustainable future.

IV. LITERATURE REVIEW

A. INTRODUCTION

A literature review is a critical tool that aids in comprehending the academic knowledge on a specific subject within the framework of a study. It facilitates the identification of research gaps in existing studies, thereby providing a summary of current knowledge and assisting in the identification of various methods, theories, and approaches to inform future research in the area concerned.

B. LITERATURE SURVEY

The following is a summary of relevant papers on carbon footprint assessment and reduction, particularly in educational institutions and the building sector:

[1] Nidhi Chauhan et al. (2024) focused on reviewing methodologies for assessing carbon emissions in educational institutions, emphasizing their potential for contributing to a sustainable planet. The study highlighted the importance of calculating carbon footprints within these institutes and discussed different approaches to identify and quantify emissions for implementing reduction strategies.

[2] Kulkarni S et al. (2019) calculated the carbon footprint of an Indian higher education institute using a bottom-up Life Cycle Analysis (LCA), identifying emission sources across GHG Protocol scopes. Recommendations included transitioning to renewable energy, using energy-efficient appliances, reducing waste, and minimizing transportation emissions.

[3] Sangwan et al. (2018) examined the carbon footprint of BITS Pilani using ISO 14064. The study identified electricity (70%) as the primary emission source, followed by transportation (16%) and food waste (10%), recommending focus on renewable energy, reduced fossil fuel use, and minimizing food waste.

[4] Robinson et al. (2018) evaluated six carbon footprint methodologies, identifying inconsistencies. They suggested standardized boundary definitions, data collection formats, and verification processes to improve comparability among universities.

[5] Kiehle et al. (2023) used a hybrid LCA and input-output method for the University of Oulu, showing electricity as the largest emission source and a 20% reduction since 2007. The study underscored the role of universities in reducing carbon footprints through sustainable infrastructure and practices.

[6] Sen et al. (2022) synthesized existing research and shared successful case studies in achieving sustainability and carbon neutrality in higher education institutions. This paper explored methodologies for assessing carbon footprint, including Scope 1, 2, and 3 emissions, emphasizing the importance of transparent and exact reporting for tracking progress towards sustainability goals.

[7] Battistini et al. (2023) focused on assessing the carbon footprint of a large university, guided by the GHG Protocol, ISO 14064, and ISO/TR 14069 to understand the environmental impact of GHG emissions.

[8] Sudarshan J. et al. (2019) aimed to measure all GHG emissions related to educational institutes, covering various scope categories under the GHG Protocol. The study utilized a Life Cycle Assessment (LCA) methodology to neutralize carbon emissions from such institutions, focusing on precise limits, emission source identification, integration, carbon footprint measurement, and results interpretation.

[9] Cano et al. (2023) examined UNE-ISO 14064-1 and the WRI/WBCSD GHG Protocol Corporate Standard for GHG emission accounting. Adherence to these globally accepted standards established the reliability and applicability of the study's findings towards achieving sustainability and carbon neutrality.

[10] Adeyeye et al. (2023) used a comprehensive approach combining the GHG Protocol Corporate Standard and LCA to calculate a university's carbon footprint, providing insights into major contributors for informed decision-making and targeted emission reduction strategies. Suggested strategies included renewable energy, sustainable transport, and waste management.

[11] Gulcimen et al. (2023) employed the LCA method for measuring university campus sustainability, an organized approach to evaluating environmental impacts across a system's entire life cycle (planning, designing, building, operating, maintaining, decommissioning, or recycling).

[12] Pandey et al. (2011) examined carbon footprint methodologies, including LCA and input-output analysis, identifying their advantages and applications in efficient carbon reduction strategies.

[13] Cooper et al. (2023) used LCA to identify electricity, transportation, and food waste as major emission sources. They advocated for stakeholder collaboration and sustainability integration in academics, noting universities' active role in paving the path for a more sustainable future.

[14] Guo et al. (2023) presented an LCA calculating carbon emissions in Chinese buildings, considering both direct and indirect emissions. They found buildings responsible for 30% of national emissions, with construction (45%) and operation (35%) phases being the largest contributors.

They identified ways to improve energy efficiency and reduce emissions using energy-efficient materials and technologies.

[15] Wiche et al. (2022) highlighted primary challenges in measuring building carbon footprints across their life cycle in Chile (applicable elsewhere), including incomplete material/method information, lack of standardized methods, accounting for embodied carbon, and variations in energy sources and network emissions.

[16] Klein-Banai & Theis et al. (2013) employed a data-driven method analyzing factors affecting GHG emissions in universities. They found correlations with institutional size (building area, student enrollment), laboratory/residential space, presence of a medical school, and faculty/staff/student commuting. Climate had a secondary impact, with physical size being the biggest factor for Scope 1 and 2 emissions.

[17] Savolainen et al. (2023) assessed carbon footprints, including direct (Scope 1) and indirect (Scope 2 and 3) emissions from waste, electricity, and other sources. They emphasized transparent reporting and data-driven values, stressing precise data collection for accurate calculations, targets, and progress monitoring, and promoting environmental responsibility through coordination.

[18] Norouzi et al. (2023) provided insights into the potential of low-energy buildings to reduce GHG emissions, estimating a building's carbon footprint using LCA. Their assessment of heating/ventilation options, electricity generation scenarios, and waste treatment alternatives revealed significant variations in carbon footprint based on technological and decarbonization pathways.

[19] Gaarder et al. (2023) provided information on the optimum insulation thickness for building envelopes in cold climates, considering embodied carbon emissions during material production and energy savings from reduced heating. They used LCA to compare environmental effects across different insulation thicknesses, materials, climates, and energy mixes.

[20] Sharma et al. (2021) aimed to understand how various tree species contribute to CO2 sequestration. They calculated Above Ground Biomass using allometric formulas and emphasized selecting species with higher carbon sequestering potential for landscape planning in urban green spaces to reduce carbon footprints.

[21] da Silva et al. (2023) evaluated studies on decarbonization methods, highlighting globally adopted sustainable practices like renewable energy, energy efficiency, eco-friendly transport, and carbon offset programs. The study also discussed the role of leadership, governance, and institutional policies in supporting effective decarbonization initiatives.

[22] Mehta et al. (2022) focused on minimizing the carbon footprint of an Indian research and educational institution. Their study involved assessing Scope 1, 2, and 3 carbon emissions, considering inclusions and exclusions, and examining carbon sinks and offsets on campus.

[23] Wang et al. (2022) investigated how turfgrass spaces (sports fields, lawns) act as significant carbon sinks, absorbing CO2. They explored how management techniques (fertilizer, irrigation, mowing height) impacted turfgrass carbon sequestration rates due to extensive root systems and high biomass production.

[24] Sirin et al. (2023) provided insights into Building Integrated Photovoltaic/Thermal (BIPV/T) systems, which simultaneously generate electricity and provide thermal comfort. Their research evaluated BIPV/T performance in terms of electricity production and thermal comfort for overall energy efficiency.

[25] Moghayedi et al. (2023) introduced retrofitting building windows by filling the air gap between glass panes with polyurethane foam (PU foam). This rapid, non-destructive, economical, and ecologically conscious technique lowered window transmittance by 25%, resulting in significant energy savings.

[26] Gao et al. (2023) provided an overview of CiteSpace and VOSviewer use in understanding carbon emissions of public buildings, emphasizing five major study areas: simulation modeling/theoretical research, energy systems, materials, retrofitting, and the use of digital technologies, structural elements, and architectural characteristics for sustainability.

[27] Ruggieri et al. (2023) highlighted the building industry's significance in achieving zero-emission targets, particularly in the EU, noting that residential and educational structures in Italy contribute substantially to energy demand and GHG emissions. They established a three-phase policy roadmap for energy renovation: market barrier reduction/financial incentives, national database creation, and promotion through public procurement.

[28] Abdelaal & Guo et al. (2021) provided an understanding of stakeholder participation in green building construction in New Zealand, including knowledge, attitudes, and practices among investors, engineers, architects, developers, government representatives, contractors, building owners, and tenants. They identified a gap between knowledge and practice due to lack of awareness regarding sustainable building materials, integrated design, and energy-efficient systems.

C. FINDINGS FROM LITERATURE REVIEW:

The extensive literature review reveals several key findings concerning carbon footprint assessment and reduction, particularly in educational institutions and the broader building sector:

1) Provides information about various carbon emission sources present in an educational institute.
2) Describes different sources based on the scopes categorized according to the GHG Protocol.
3) Specifies various formulas for calculating carbon emissions from the identified sources, along with information about various conversion factors to convert different GHGs into Carbon Emission Equivalents.
4) Determines the overall amount of carbon emissions using a variety of techniques and assists in comparing them.
5) Determines different carbon sinks for carbon sequestration from the institute, and calculate carbon sequestration potential using various allometric equations.
6) Makes recommendations for different carbon offsets both inside and outside the institute's boundaries.
7) Highlights strategies to make effective use of different resources and contribute to their conservation through a variety of sustainable methods.

D. GAP AREA IDENTIFIED:

Despite substantial technological advancements in calculating carbon emissions in buildings and identifying various sinks, considerable gaps remain in the existing literature:

1) Research has been done using Life Cycle Analysis, but none of the literature suggested a comparison based on manual analysis using a bottom-up approach, following ISO 14064-1 and utilizing conversion factors from the GHG Protocol Corporate Standard (a joint initiative by the World Business Council for Sustainable Development (WBCSD) and World Resources Institutes (WRI), and various other institutes). This indicates a lack of studies comparing manual, bottom-up calculations with LCA results.
2) Although extensive efforts have been made to calculate emissions from various scopes as per GHG Protocol Corporate Standards, carbon emissions from personal vehicles in Scope 3 have been excluded from almost all studies due to a lack of accurate data. Efforts in this direction could yield more practical and comprehensive data.
3) Various studies have suggested carbon sinks and carbon offsets separately. Their integrated analysis and approach would provide a more comprehensive solution for developing a balanced equation towards sustainable educational institutes.

V. CONCLUSION

The global imperative to combat climate change necessitates a concerted effort to reduce greenhouse gas emissions, with the building sector playing a pivotal role. This review underscores the significant contribution of buildings to global energy demand and CO2 emissions, highlighting the critical need for comprehensive carbon footprint assessment and robust reduction strategies. The GHG Protocol provides a foundational framework for categorizing emissions, although challenges persist, particularly in accurately quantifying indirect Scope 3 emissions.

The literature reveals a growing body of research focused on assessing and mitigating carbon footprints within educational institutions, advocating for transitions to renewable energy, enhanced energy efficiency, sustainable transportation, and the development of carbon sinks through afforestation. However, identified research gaps emphasize the need for comparative studies using standardized manual calculation methods, more accurate methodologies for Scope 3 emissions from personal commuting, and an integrated approach to leveraging carbon sinks and offsets for holistic sustainability.

Ultimately, achieving "NET ZERO" targets and ensuring a sustainable future demands continuous innovation, collaborative efforts across all stakeholders, and the consistent implementation of data-driven strategies. By addressing these identified gaps and fostering a culture of environmental responsibility, the building sector, especially educational institutions, can lead the way in mitigating climate change and promoting a more sustainable planet for generations to come.

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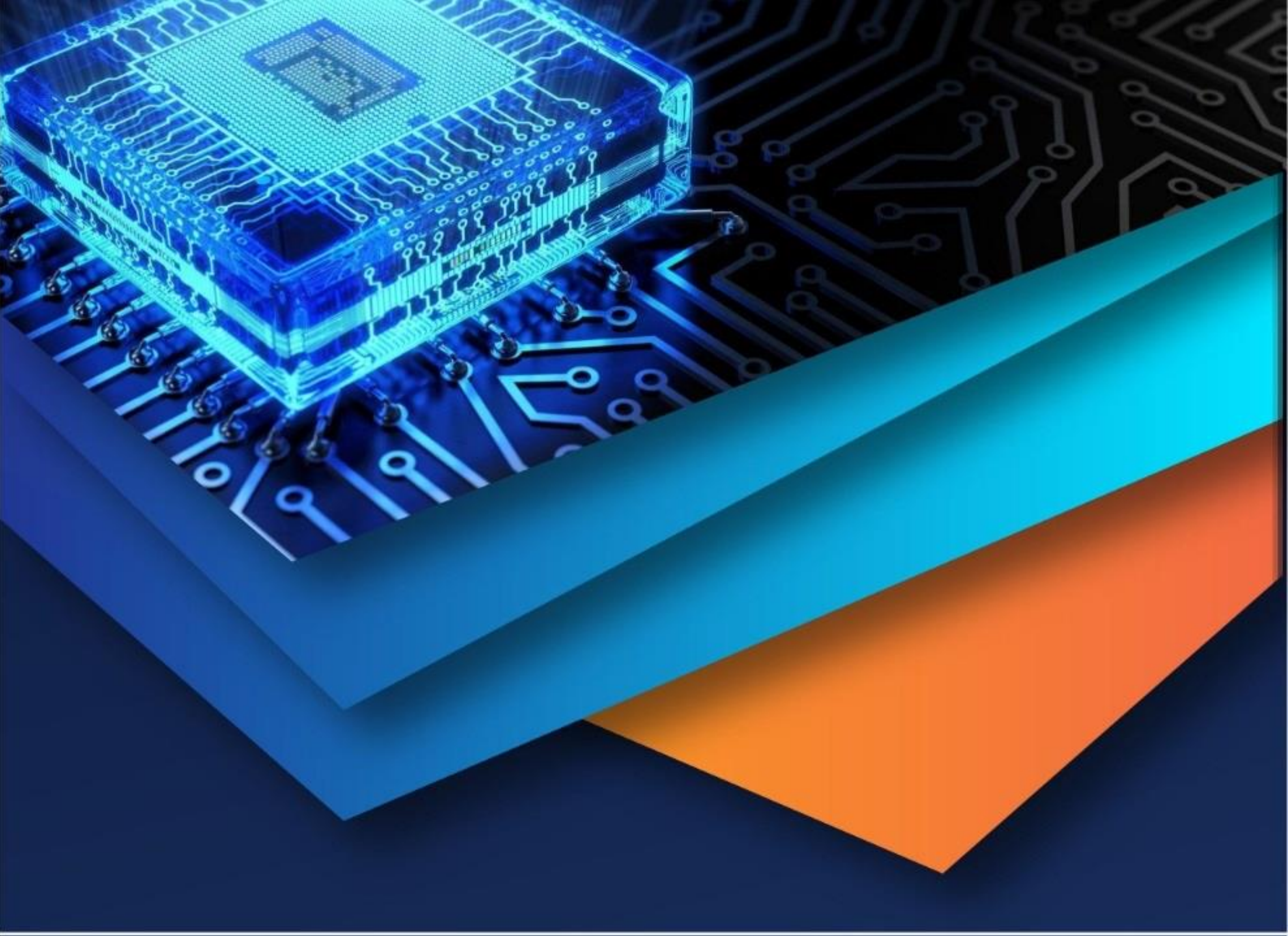

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