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Multi-Objective Seismic Optimization of RC High-Rise Buildings Using NSGA-III

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Abstract: This study presents an integrated framework for seismic performance assessment and multi-objective optimization of a G+12 reinforced concrete (RC) high-rise residential building using STAAD.pro and the NSGA-III algorithm. This research contributes a reproducible, automation-based framework for sustainable and code-compliant seismic design, facilitating performance-driven decisions for civil engineers, planners, and stakeholders. Future work may extend toward lifecycle cost modeling, nonlinear time-history analysis, and soil-structure interaction.
Keywords: Seismic Loads; Non-Seismic Loads; Structural Analysis; High-Rise Building Design.

I. INTRODUCTION

India, being a tectonically active region, is prone to frequent seismic events, making earthquake-resistant design of high-rise buildings not only important but essential for public safety, economic sustainability, and infrastructure resilience. In this section highlights the growing importance of integrating seismic performance assessment with multi-objective optimization in the structural design of high-rise RC buildings. It underscores the necessity of considering both static and dynamic loading conditions, adhering to Indian standards, leveraging advanced simulation software, and incorporating modern optimization algorithms. The convergence of these domains presents an opportunity to revolutionize how buildings are designed—moving from prescriptive methods to intelligent, data-driven solutions that prioritize both safety and sustainability.

II. RESEARCH OBJECTIVES

The primary aim of this research is to develop an integrated framework for seismic performance assessment and multi-objective optimization of a G+12 reinforced concrete (RC) high-rise residential building using STAAD.pro and NSGA-III. Specific objectives include:

1) To model and simulate a G+12 RC high-rise building under seismic and non-seismic loading conditions using STAAD.pro as per IS 1893:2016 and IS 875:1987.
2) To analyze the structural responses (displacement, axial force, shear force, bending moment, and plate stress) under both static and dynamic loads.
3) To evaluate the influence of seismic design on material consumption (steel and concrete), construction cost, and environmental impact (CO_2 emissions).
4) To implement a Python-based multi-objective optimization framework using the NSGA-III algorithm to simultaneously optimize six conflicting objectives: total cost, displacement, axial force, base shear, inter-story drift, and embodied CO_2 emissions.
5) To identify Pareto-optimal design solutions and recommend a balanced design alternative using decision-making methods such as the Weighted Sum Method (WSM) and sensitivity analysis.
6) To statistically validate the differences in structural behavior under seismic and non-seismic scenarios through hypothesis testing and comparative performance analysis.

III. LITERATURE REVIEW

In recent years, a growing body of research has explored the application of multi-objective optimization techniques and seismic simulation in the structural design of high-rise reinforced concrete (RC) buildings. These studies demonstrate the versatility of algorithms like NSGA-III in balancing competing performance, cost, and sustainability objectives in both new constructions and retrofitting projects.

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Razmi, Rahbar, and Bemanian (2022) developed a PCA-ANN integrated NSGA-III framework to optimize energy efficiency, daylighting, and thermal comfort in dormitory buildings. While the objectives were environmental rather than structural, the study exemplified the ability of NSGA-III to navigate complex design spaces involving multiple conflicting goals.

Tanhadoust, Madhkhan, and Nehdi (2023) conducted a two-stage optimization of RC buildings using NSGA-III to minimize structural cost and water footprint. Their findings highlighted that environmental impact can be simultaneously addressed with economic objectives through modern optimization approaches.

Park, Choi, and Choi (2024) applied NSGA-III for seismic retrofitting of RC buildings using fiber-reinforced polymer (FRP) jacketing. Their work showcased NSGA-III's capacity to optimize retrofitting interventions based on resilience, cost, and intervention scope under seismic loading.

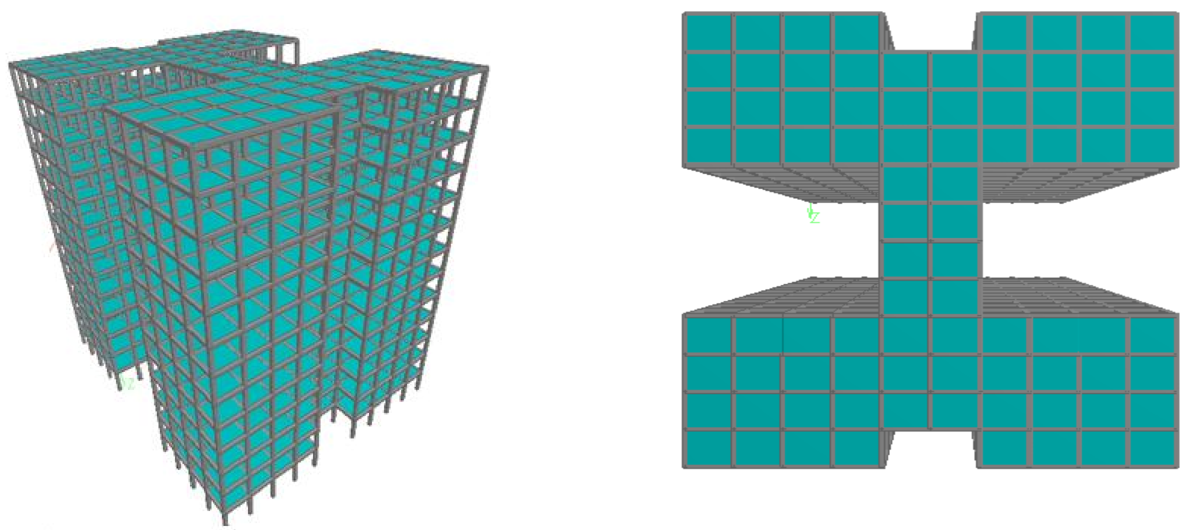
Song, Chen, and Wang (2024) proposed a modified NSGA-III model for optimizing carbon emissions, cost, and schedule in prefabricated buildings, further expanding NSGA-III’s applicability to sustainability-aware project-level decisions.

Zhang and Zhuang (2025) optimized high-rise office building performance using NSGA-III and machine learning, balancing energy usage, thermal comfort, and lighting efficiency—underscoring the relevance of MOO in tall building design.

These studies provide a strong precedent for integrating seismic simulation with NSGA-III-based optimization in high-rise RC buildings, though few address seismic performance, cost, and environmental criteria concurrently.

IV. RESEARCH METHODOLOGY

The approach used to analyze and compare the effects of seismic and non-seismic loads on a G+12 residential structure using STAAD.pro software. The methodology includes a detailed description of the building model, applied loads, software setup, and analytical techniques. The study employs dynamic analysis for seismic loads and static analysis for non-seismic loads to assess the structural response and safety of the high-rise building.



Elevation and Plan View of the G+12 Residential Structure

A. Software Model Setup in STAAD.pro

The structural analysis is conducted using STAAD.pro, a widely adopted commercial software for the modeling, analysis, and design of buildings under various loading conditions. In this study, a G+12 residential RC structure is modeled in STAAD.pro to simulate realistic structural behavior under both seismic and non-seismic scenarios. To evaluate the impact of seismic and non-seismic loads on the G+12 residential structure, the study compares key structural response parameters.

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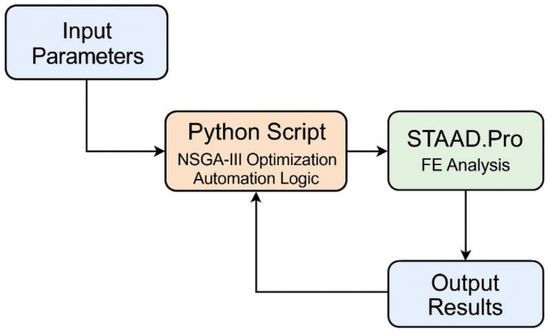
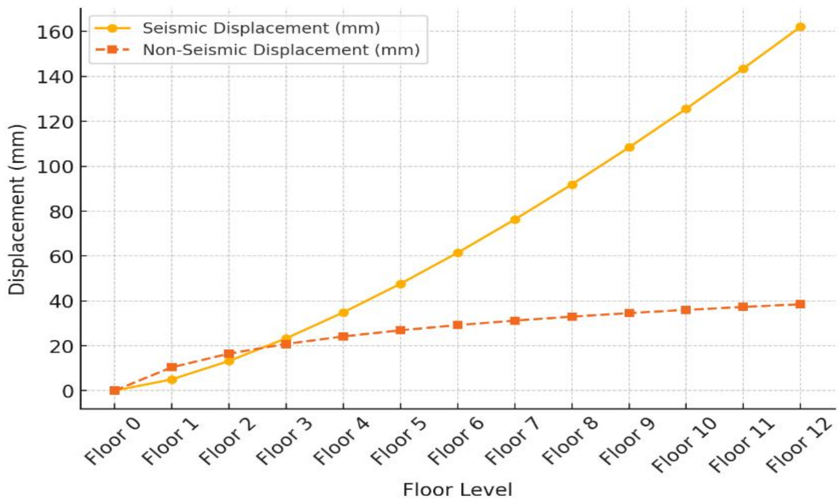


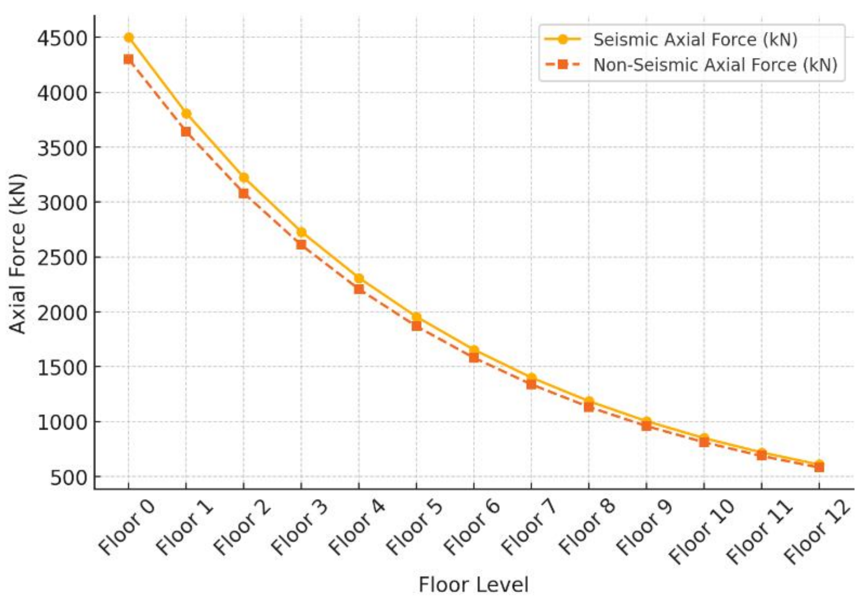
Automation Flowchart Linking NSGA-III and STAAD.pro

V. RESULTS AND DISCUSSION

This section presents the results of the seismic and non-seismic load analysis performed on the G+12 residential structure using STAAD.pro software.



Displacement Diagram from STAAD.pro Analysis



Axial Force Distribution in Columns

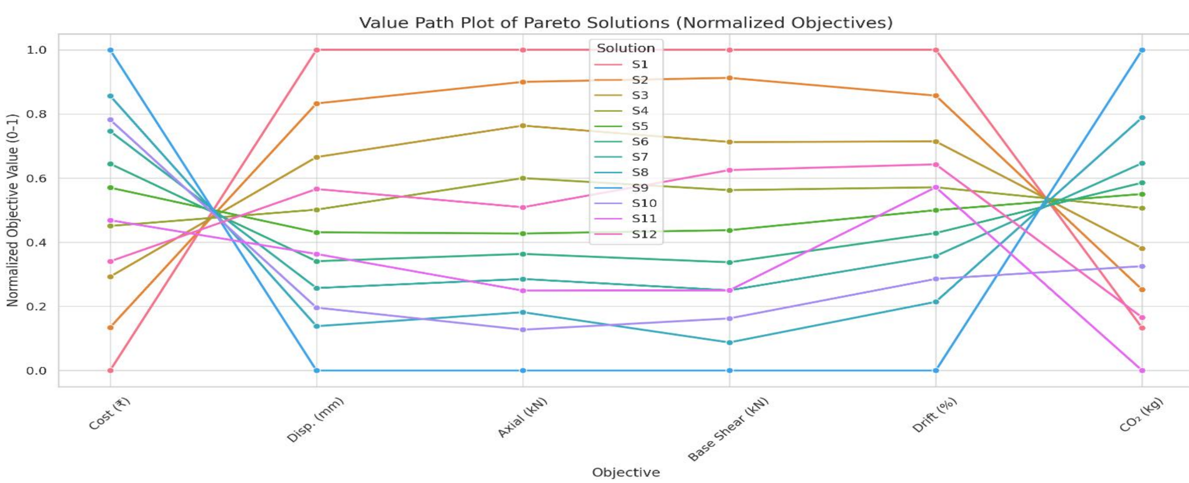
The optimization targeted six objectives: minimizing total material cost, top-floor displacement, axial force in columns, base shear, inter-story drift ratio, and CO_2 emissions. These goals collectively address structural efficiency, seismic performance, occupant safety, and environmental sustainability.

Optimization Objectives and Their Design Rationale

Objective ID	Objective Function	Type	Unit	Rationale
OBJ1	Minimize Total Material Cost (Steel + Concrete)	Minimize	₹	Reduces financial burden
OBJ2	Minimize Top-Floor Lateral Displacement	Minimize	Mm	Improves seismic performance and serviceability
OBJ3	Minimize Maximum Axial Force in Columns	Minimize	kN	Prevents column buckling and crushing
OBJ4	Minimize Base Shear	Minimize	kN	Reduces seismic demand on foundations
OBJ5	Minimize Maximum Inter-Story Drift Ratio	Minimize	%	Ensures occupant comfort and damage control
OBJ6	Minimize CO_2 Emissions from material usage	Minimize	kg CO_2	Addresses sustainability and carbon-conscious design

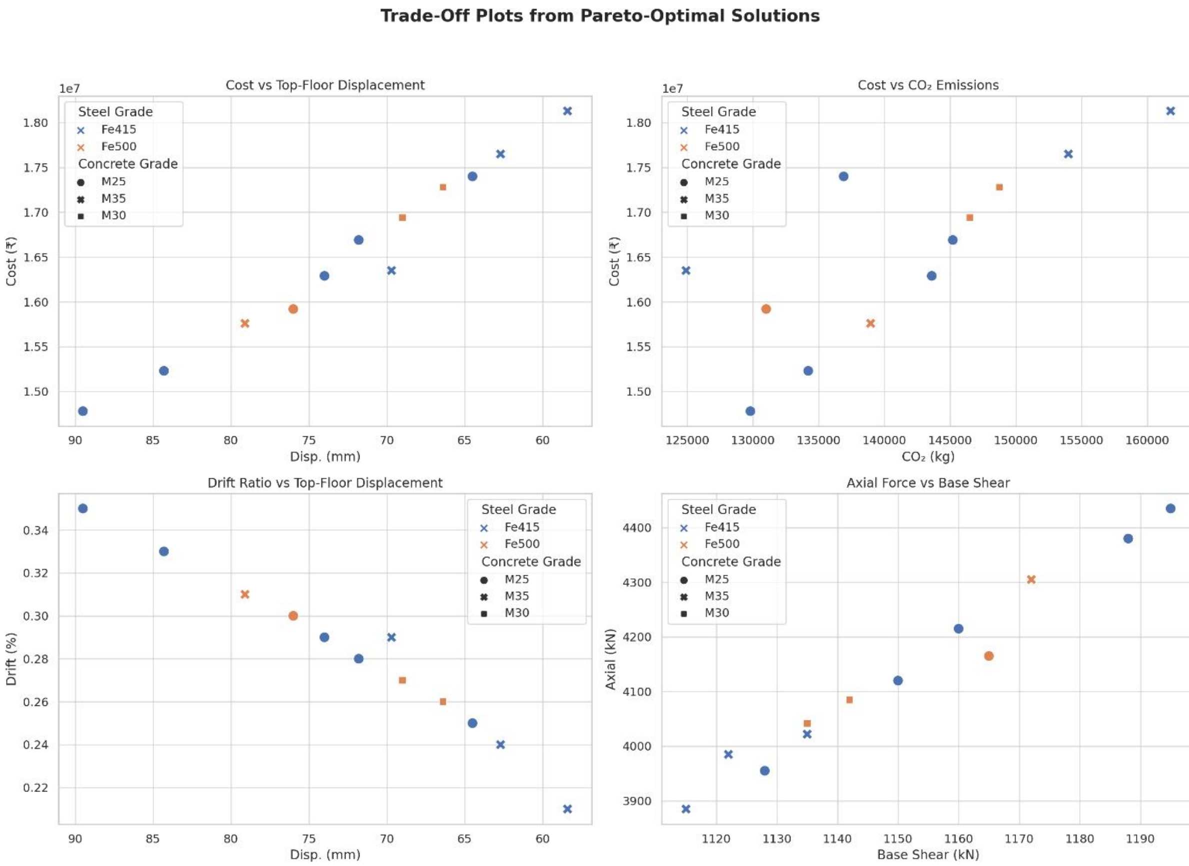
Pareto-Optimal Design Solutions with Objective Values and Decision Variables

ID	Cost (₹)	Disp. (mm)	Axial (kN)	Base Shear (kN)	Drift (%)	CO_2 (kg)	Col b (mm)	Col d (mm)	Beam b (mm)	Beam d (mm)	Slab thk (mm)	Steel Grade	Concrete Grade	ρ (%)
S1	1,47,80,000	89.5	4435	1195	0.35	129,800	442	571	267	357	173	Fe415	M25	1.35
S2	1,52,30,000	84.3	4380	1188	0.33	134,200	518	544	270	534	179	Fe415	M25	2.16
S3	1,57,60,000	79.1	4305	1172	0.31	138,950	664	615	335	493	180	Fe500	M35	1.45
S4	1,62,90,000	74.0	4215	1160	0.29	143,600	464	511	443	515	147	Fe415	M25	1.58
S5	1,66,90,000	71.8	4120	1150	0.28	145,200	483	625	494	532	145	Fe415	M25	1.80
S6	1,69,40,000	69.0	4085	1142	0.27	146,500	496	727	482	514	147	Fe500	M30	1.80
S7	1,72,80,000	66.4	4042	1135	0.26	148,750	508	738	373	552	170	Fe415	M30	1.92
S8	1,76,50,000	62.7	3985	1122	0.24	154,000	464	682	345	570	180	Fe415	M25	2.02
S9	1,81,30,000	58.4	3885	1115	0.21	161,780	648	492	354	526	145	Fe500	M35	1.40
S10	1,74,00,000	64.5	3955	1128	0.25	136,900	480	608	439	587	174	Fe415	M35	1.85
S11	1,63,50,000	69.7	4022	1135	0.29	124,900	603	617	479	572	178	Fe500	M25	2.50
S12	1,59,20,000	76.0	4165	1165	0.30	131,000	540	622	472	525	140	Fe415	M25	1.78



Value-Path Plot

The trade-off relationships among the six objectives are visualized in figure.



Trade-Off Plots among Objectives

The comparative analysis of seismic and non-seismic loads on the G+12 residential structure using STAAD.pro reveals significant differences in structural behavior under varying loading conditions. Seismic forces result in substantially higher displacements, axial forces, shear forces, bending moments, and plate stresses compared to static loads, reinforcing the necessity of seismic-resistant design strategies for high-rise buildings in earthquake-prone areas.

VI. CONCLUSION

This research presents a comprehensive methodology for integrating seismic performance evaluation with many-objective optimization to support informed decision-making in the design of RC high-rise buildings. By combining STAAD.pro-based structural simulation with the Non-Dominated Sorting Genetic Algorithm III (NSGA-III), the study successfully addressed multiple conflicting design criteria including cost, structural safety, and sustainability.

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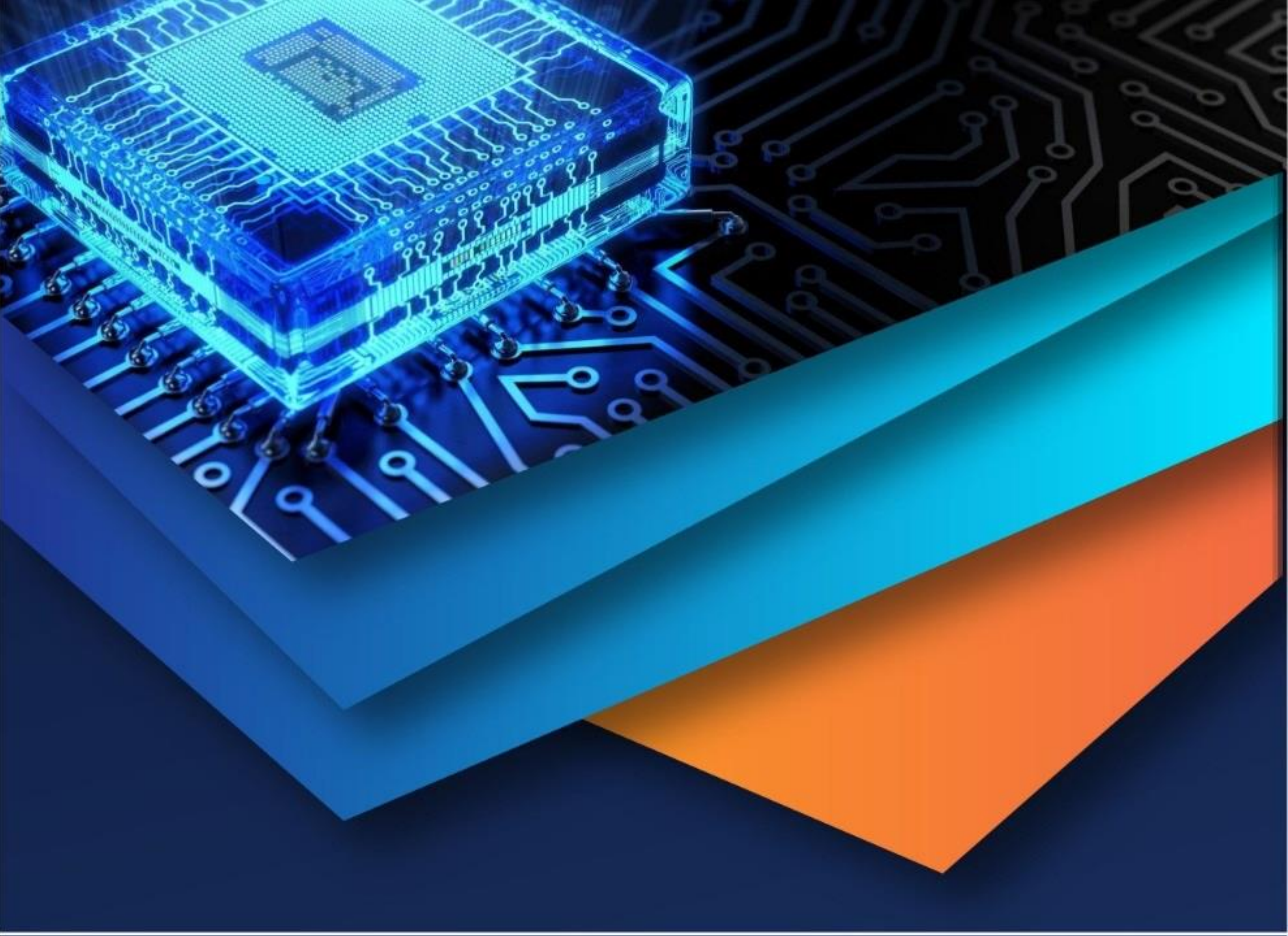

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