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Modular Construction in Portugal: Analysis of Advantages, Structural Typologies, and Technical Challenges

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Abstract*: Modular construction has emerged as a promising alternative to traditional building methods in Portugal, driven by the need for faster, more sustainable, and economically viable solutions. This article critically analyzes the advantages, structural typologies, and technical challenges associated with this methodology. Through technical review and analysis of practical case studies, steel, precast concrete, CLT timber, and hybrid systems were evaluated based on criteria such as seismic resistance, sustainability, assembly time, and connection complexity. The results indicate that modular construction offers significant gains in efficiency, budget control, and environmental performance, especially when integrated with technologies such as BIM and factory automation. However, relevant obstacles remain, including cultural barriers, legislative gaps, logistical difficulties, and technical limitations specific to each structural typology. Cases such as the B&B Hotel in Guimarães demonstrate the potential of the modular approach, while projects like the one in Loures highlight the challenges of its implementation. The article concludes that, to consolidate modular construction in Portugal, it is essential to promote technical standardization, adapt financing models, and invest in structural innovation. The trend points to the growing use of steel and CLT in sustainable and seismic-resistant solutions, reinforcing the strategic role of modular construction in the future of Portuguese civil engineering.

***Keywords:* Modular construction; Structural typologies; Sustainability; Technical challenges; Civil engineering; Portugal**

I. INTRODUCTION

In recent decades, modular construction has been establishing itself as a viable and innovative alternative to traditional construction, especially in contexts that demand fast execution, environmental sustainability, and strict cost control. In countries such as the United Kingdom, Sweden, and the Netherlands, this construction method already accounts for a significant portion of the civil construction market, driven by technological advancements and growing environmental awareness.

In Portugal, although the sector is still in a consolidation phase, there has been a significant increase in interest in industrialized solutions, both in the residential segment and in institutional and commercial projects. According to recent market data, demand for modular housing grew by more than 200% between 2024 and 2025, reflecting a shift in mindset and greater acceptance by the public, designers, and real estate developers.

This evolution, however, is not without challenges. Despite its evident advantages — namely construction speed, budget predictability, and architectural flexibility — modular construction still faces various limitations, particularly regarding its structural component. Issues such as the seismic behavior of the modules, the durability and efficiency of structural connections, as well as restrictions imposed by technical standards and national regulations, present significant obstacles to its large-scale adoption.

This article aims to critically analyze the potential of modular construction in Portugal, with a special focus on the most commonly used structural typologies, their technical and functional advantages, and the main structural and regulatory challenges associated. Through a technical and well-founded approach, the intention is to contribute to a deeper understanding of the role that this construction methodology can play in the future of Portuguese civil engineering.

II. MATERIALS AND METHODS

This article adopts a technical-analytical approach, based on literature review, regulatory analysis, and practical case studies, with the aim of assessing the potential of modular construction in Portugal. The methodology was structured into four main stages: theoretical survey, definition of comparative criteria, regulatory analysis, and analysis of real case studies.

A. Theoretical and Documentary Survey

The development of the work was based on an extensive review of technical and scientific literature, including articles published in specialized journals, technical reports from European institutions, and regulatory documents. Both national and international sources were consulted, addressing the evolution of modular construction, its applications, advantages, limitations, and structural performance. This review made it possible to identify the main structural typologies used in Portugal: steel structures, precast concrete, CLT (Cross-Laminated Timber), and hybrid systems.

B. Comparative Analysis Criteria

Based on the literature and the data collected, the following technical criteria were defined for the comparative analysis of the structural typologies:

- Structural weight
- Execution cost
- Assembly time
- Seismic resistance
- Environmental sustainability
- Complexity of structural connections
- Environmental sensitivity (humidity, corrosion, fire)
- Maintenance requirements
- Logistical and transportation ease

These criteria were applied qualitatively and comparatively, based on available technical data, European standards, and practical observations.

C. Technical Standards and Tools Used

The technical analysis was based on the following regulatory documents:

- EN 1992 (Eurocode 2) – Design of concrete structures
- EN 1993 (Eurocode 3) – Design of steel structures
- EN 1995 (Eurocode 5) – Design of timber structures

Technological tools considered included:

- BIM (Building Information Modeling) – for specialty coordination and conflict simulation
- Automation and robotics – applied to the factory production of modules
- Numerical modeling and experimental testing – for connection analysis and structural behavior

D. Case Studies

Two real-world projects were selected for qualitative analysis:

- B&B Hotel Guimarães: A successful project using the hybrid CREE system (timber + concrete), noted for its fast execution (structure assembled in 8 working days), high-quality control, integration of specialties, and strong environmental performance.
- Modular Housing Project in Loures: A pilot project in social housing that faced technical and institutional obstacles, such as licensing delays, logistical difficulties, technical incompatibilities, and unforeseen cost overruns.

These cases helped validate the analysis criteria and illustrated the critical success and failure factors in the adoption of modular construction in Portugal.

III. RESULTS

A. Potential of Modular Construction in Portugal

Modular construction represents a paradigm shift in civil engineering by introducing a more industrialized, efficient, and sustainable production model. In Portugal, this construction method has been gaining traction, not only as a response to the housing crisis but also as a technically viable alternative for various types of buildings.

1) General Advantages

1. Efficiency and Speed of Construction

Modular construction allows for a significant reduction in construction time, since the modules are produced in a factory simultaneously with site preparation. Studies indicate that total execution time can be reduced by up to 50–60% compared to traditional methods. For example, modular residential buildings can be completed in 4 to 6 months, while conventional projects may exceed 18 months.

In addition, production in a controlled environment reduces the risks associated with weather delays, execution errors, and material shortages.

2. Controlled Costs and Budget Predictability

The standardization of components and the repetition of processes in a factory environment allow for greater cost control, with less material waste and less need for rework. Budget predictability is a critical advantage in public and private projects with tight financial plans.

3. Sustainability and CO_2 Reduction

Modular construction helps reduce the ecological footprint of the construction industry. The use of recyclable materials (such as steel) or renewable ones (such as CLT timber), combined with reduced waste and lower energy consumption during the construction phase, makes this method more sustainable. Moreover, the energy efficiency of modular buildings tends to be higher, with better thermal performance and the possibility of integrating passive and active systems (solar panels, natural ventilation, etc.).

4. Architectural and Modular Flexibility

Modules can be repositioned, expanded, or dismantled, allowing buildings to adapt to new needs over time. This flexibility is particularly useful in contexts such as schools, hospitals, temporary accommodations, or social housing.

5. Technological Innovation

Modular construction benefits from the integration of technologies such as:

- BIM (Building Information Modeling): for coordination between specialties and early clash detection.
- Automation and robotics in module production.
- Smart systems for energy and comfort management.

2) Advantages by Structural Type

Steel Structures

Steel structures are widely used in modular construction due to their high mechanical resistance and relative lightness, which facilitates transportation and module assembly. Their ductility makes them especially effective in seismic zones, as they allow energy dissipation without collapsing, as provided in Eurocode 3 (EN 1993). Additionally, steel enables greater architectural freedom, with wide spans and slender structures. The fast assembly, combined with the possibility of prefabricating highly accurate structural elements, significantly reduces construction time.

Precast Concrete Structures

Precast concrete stands out for its robustness, durability, and excellent thermal and acoustic performance. It is ideal for buildings requiring comfort and fire resistance, such as schools, hospitals, or collective housing. Factory production ensures strict quality control and proper curing, resulting in elements with high resistance and low variability. Despite its weight—requiring more robust foundations—concrete offers superior structural rigidity and is governed by Eurocode 2 (EN 1992).

Timber Structures (CLT – Cross-Laminated Timber)

Cross-laminated timber (CLT) is an increasingly valued solution for its sustainability, lightness, and rapid assembly. As a renewable material with a low carbon footprint, it contributes to more ecological buildings. Its lightness makes transport easier and reduces foundation requirements. Moreover, CLT shows good thermal and acoustic performance, making it ideal for single-family housing, rural tourism, and small-scale buildings. Eurocode 5 (EN 1995) provides guidelines for its structural design.

Hybrid Systems (Combination of Materials)

Hybrid systems combine different structural materials—such as steel with concrete or steel with wood—to take advantage of the specific qualities of each. For instance, steel can be used for the main structure (for its strength and lightness) and concrete for rigid cores or slabs (for its thermal inertia and insulation). This approach allows for optimizing the overall structural performance in terms of both resistance and comfort. However, it requires a high degree of technical coordination, especially at the junctions between materials with different behaviors.

B. Obstacles to Modular Construction in Portugal

Despite its recognized potential, modular construction in Portugal faces a range of structural, technical, and cultural obstacles that hinder its large-scale adoption. These challenges go beyond public perception or the legal framework, extending to critical aspects of structural performance, such as material durability, connection efficiency, and compatibility between different construction systems. Overcoming these barriers is essential to consolidate modular construction as a viable and sustainable alternative to traditional methods.

1) General Challenges

1. Cultural Barriers and Market Resistance

Modular construction is still often associated with temporary or low-quality solutions, such as repurposed containers. This perception, rooted in a lack of technical information and the absence of widely publicized success stories, generates resistance among developers, designers, and end users. The lack of specific training in civil engineering and architecture curricula exacerbates this gap, limiting the technical capacity to design and implement modular systems with rigor and innovation.

2. Financing and Property Valuation

The absence of standardized criteria for valuing modular buildings poses a significant obstacle to financing. Many banks are reluctant to finance projects involving unconventional materials, such as CLT wood or hybrid systems, due to the difficulty of estimating their market value and longevity. This uncertainty compromises the economic viability of modular developments, discouraging potential investors.

3. Legal Framework and Licensing

Although modular buildings fall under the Urbanization and Building Legal Framework (RJUE), the lack of specific technical regulation for modular systems creates uncertainties in the licensing process. The absence of adapted national standards forces designers to interpret Eurocodes, which can result in discrepancies between municipalities and significant delays. Furthermore, ambiguity in classifying modules as “permanent” or “temporary” structures—depending on the municipality—generates legal insecurity.

4. Logistics, Transport, and Assembly

Modular construction requires rigorous logistical planning, given the need to transport and assemble large elements with millimetric precision. Key requirements include:

- Properly dimensioned access roads;
- Special transport permits;
- High-capacity lifting equipment;
- Efficient coordination between transport and assembly teams.

During assembly, the geometric precision of structural connections is critical. Small deviations can compromise structural continuity, sealing, and seismic performance. The shortage of specialized modular assembly labor, especially outside major urban centers, is another limiting factor.

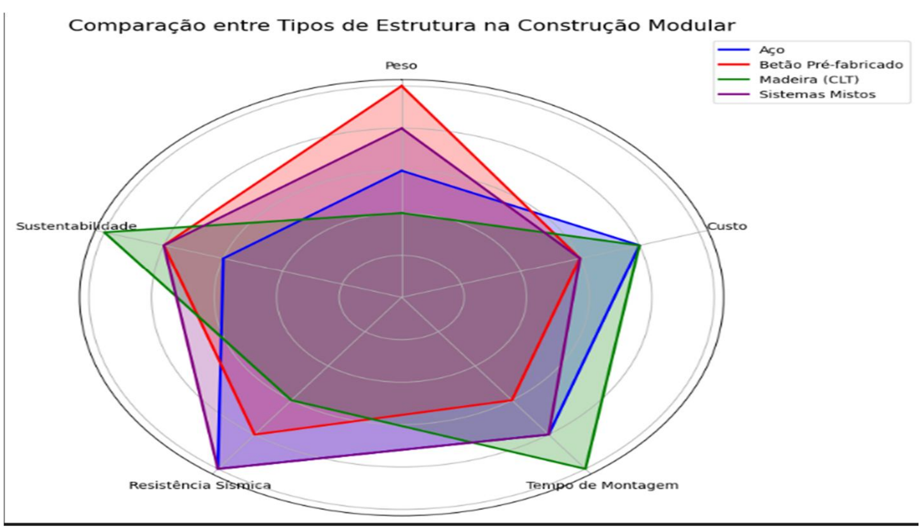

Figure 1 – Comparison of the technical performance of different modular structural systems.

2) Technical Interpretation

- Steel Structures: Stand out for their high seismic resistance and fast assembly, making them particularly effective in urban settings and areas with high seismic activity. Their environmental performance is considered moderate due to the high embodied energy involved in steel production.
- Precast Concrete Structures: Offer excellent thermal performance and high fire resistance, characteristics that make them suitable for permanent buildings with high comfort requirements. However, their heavy weight limits logistical flexibility and increases demands on foundations.
- CLT Timber Structures: Notable for their sustainability and lightness, enabling extremely fast assembly. They are ideal for environmentally focused projects. However, they have structural limitations in large-scale buildings and require specific durability measures, especially protection against moisture and fire.
- Hybrid Systems: Provide a robust technical balance, combining strength, lightness, and good environmental performance. They are recommended for projects with high structural demands, although they entail greater design complexity and higher costs, mainly due to the need to reconcile materials with differing behaviors.

C. Comparative Analysis of Technical Challenges by Structural Type

The evaluation of the technical challenges associated with different modular structural typologies makes it possible to identify the specific limitations of each system and guide their application according to the project context. The analysis considers five fundamental criteria: connection complexity, environmental sensitivity, structural weight, ease of assembly, and maintenance requirements. The following figure presents a radar chart that synthesizes the technical demand level of each structural system according to these parameters, enabling a clear and well-founded comparative assessment.

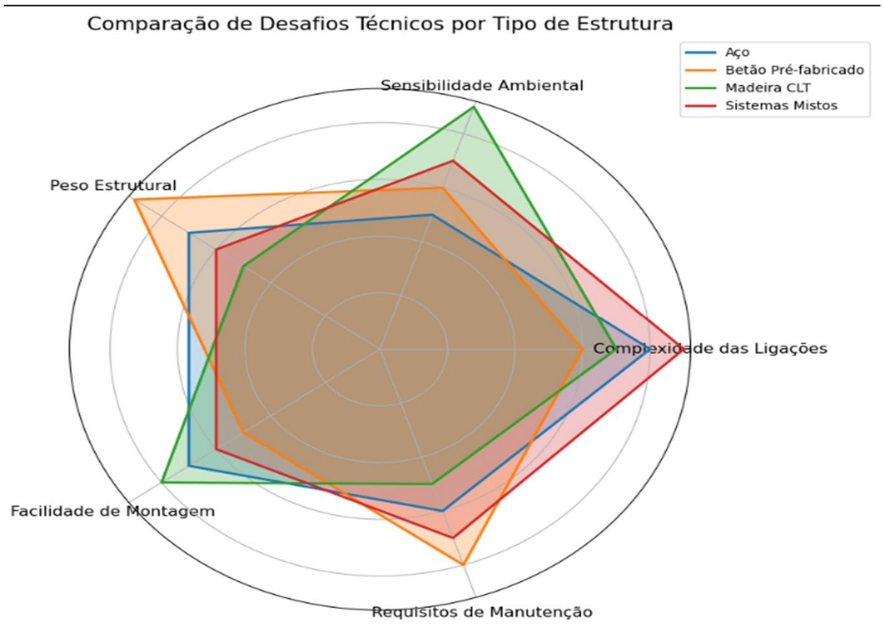

Figure 2 – Comparative analysis of technical challenges by modular structure type

Technical Interpretation

- Steel Structures: Present high complexity in structural connections, requiring millimetric precision and specialized labor. Although the weight is moderate, assembly is relatively efficient. Sensitivity to corrosion requires the application of anti-corrosion treatments and regular maintenance, especially in aggressive environments. They are suitable for buildings with high seismic requirements but demand rigorous technical planning.
- Precast Concrete Structures: Characterized by high structural weight, which imposes greater demands on foundations and the logistics of transport and assembly. Connections between modules are less complex, but joints require special attention to avoid cracking and loss of continuity. They offer good environmental resistance and low maintenance requirements, making them suitable for permanent buildings with high robustness.

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- CLT Timber Structures: Stand out for their lightness and ease of assembly, allowing for fast and clean execution. However, they are highly sensitive to moisture and fire, requiring adequate protection and preventive maintenance. Although the structural connections are lighter, they require experimental validation to ensure seismic performance. These structures are ideal for sustainable small- to medium-scale projects.
- Hybrid Systems: Combine different materials, increasing the complexity of connections and the need for compatibility between elements with distinct behaviors. They exhibit balanced performance in terms of weight, assembly, and maintenance, but demand a high degree of technical coordination and detailed project planning. They are recommended for buildings with specific structural requirements or innovative architectural solutions.

D. Practical Cases in Portugal

Modular construction has been gradually establishing itself in the national landscape, with examples that illustrate both its potential and the challenges it still faces. The analysis of real-world cases allows for a better understanding of the success conditions and critical factors that can compromise the effectiveness of this construction methodology.

Success Case: B&B Hotel Guimarães

The B&B Hotel in Guimarães represents a landmark success story in the application of modular construction in Portugal. Developed by the Casais Group, this project was executed using the CREE hybrid system — a construction solution that combines timber and concrete, with a strong emphasis on sustainability and the industrialization of the construction process.

The building, with 95 rooms, was constructed using prefabricated modules in a factory environment and assembled on-site within an extremely short time frame. The structure was erected in just 8 working days, demonstrating a high degree of efficiency and planning.

The main factors contributing to the success of this project include:

- Speed of execution: Module assembly was completed in just a few weeks, allowing a significant reduction in the overall construction timeline compared to traditional methods. This speed was essential to ensure a quicker return on investment.
- Quality control: Factory production ensured a high level of standardization and control over finishes, technical installations, and thermal and acoustic performance. The uniformity of components and continuous inspection significantly reduced non-conformities on-site.
- Sustainability: Modular construction minimized on-site waste and reduced environmental impact both during the construction phase and in the building's operation. The CREE system contributed to a more than 60% reduction in carbon footprint compared to conventional solutions.
- Logistical efficiency: Rigorous planning of transport and module assembly allowed for sequential and uninterrupted execution, maximizing productivity on-site and reducing risks associated with handling large components.
- Integration of specialties: Electrical, plumbing, and HVAC systems were pre-integrated into the modules, significantly reducing the need for post-assembly interventions. This approach facilitated team coordination and minimized clashes between specialties.

Figure 1 – Assembly of the B&B Hotel Guimarães modules.

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Figure 2 – Structure under assembly of the B&B Hotel Guimarães

Figure 3 – Final façade of the B&B Hotel Guimarães

This project demonstrates that modular construction, when combined with a strategy of sustainability, innovation, and technical coordination, can effectively meet the demands of the hotel sector. The experience of the Casais Group with the CREE system positions it as one of the main promoters of industrialized construction in Portugal, paving the way for a new generation of sustainable, efficient, and technologically advanced buildings.

Difficulty Case: Modular Housing Project in Loures (Lisbon)

A representative case of the difficulties faced in adopting modular construction in Portugal occurred in the municipality of Loures, where a pilot project for social housing using prefabricated modules was promoted. Despite the intention to accelerate the housing response and reduce costs, the project encountered several obstacles that compromised its initial goals.

Key issues reported include:

- Licensing delays: The absence of specific regulations for modular construction led to legal uncertainties and required case-by-case interpretations by municipal authorities, significantly delaying the start of construction.
- Technical incompatibilities: The project was originally designed for traditional construction and only later adapted to the modular approach, which resulted in difficulties in aligning the structural systems with technical installations.
- Logistical problems: Delivery and assembly of the modules faced constraints due to inadequate access routes and the need for specific lifting equipment that had not been foreseen.
- Institutional resistance: Some involved entities expressed skepticism regarding the durability and quality of the modular solution, leading to additional requirements for testing and certifications.
- Unforeseen cost overruns: The lack of prior experience with this type of construction resulted in planning and budgeting errors, which ended up negating some of the expected savings.

This case shows that although modular construction offers clear advantages, its successful implementation depends on an integrated approach from the design phase, a suitable legal framework, and a supply chain prepared to meet the specific requirements of this type of construction.

IV. CONCLUSIONS

The analysis developed throughout this article allows us to conclude that modular construction represents a technically viable, economically competitive, and environmentally sustainable solution for the construction sector in Portugal. Its growing adoption, driven by technological advances and the need for faster and more efficient responses to housing demand, confirms its potential as a solid alternative to traditional construction.

The viability of modular construction in the national territory is increasingly evident, as demonstrated by the success cases analyzed. However, its consolidation requires a structural transformation in the sector, including:

- Legislative and regulatory adaptation: There is an urgent need to create specific technical standards for modular systems, as well as to standardize licensing criteria across municipalities. This regulatory clarity is essential to reduce legal uncertainty and speed up approval processes.
- Restructuring of financing models: Banks and property appraisers must adapt their criteria to the reality of industrialized construction, recognizing the value and durability of modular buildings. Without such recognition, many economically viable projects will continue to face credit access barriers.
- Investment in technology and structural innovation: The development of more efficient, resistant, and easy-to-assemble connection systems is fundamental to ensuring the safety and durability of modular structures. Applied research, combined with digitalization (BIM, automation, smart monitoring), will be decisive for the sector's evolution.
- Trend toward the use of sustainable and seismic-resistant materials: The increased use of steel and CLT timber structures reflects a clear commitment to lightweight, recyclable solutions with good seismic performance. When integrated into hybrid or mixed systems, these materials help optimize both the structural and environmental behavior of buildings.

In short, modular construction has the potential to redefine the landscape of civil engineering in Portugal. To realize this potential, a joint effort is needed among designers, manufacturers, regulatory bodies, and developers. Only then will it be possible to overcome current challenges and transform modular construction into a common, efficient, and valued practice in the national market.

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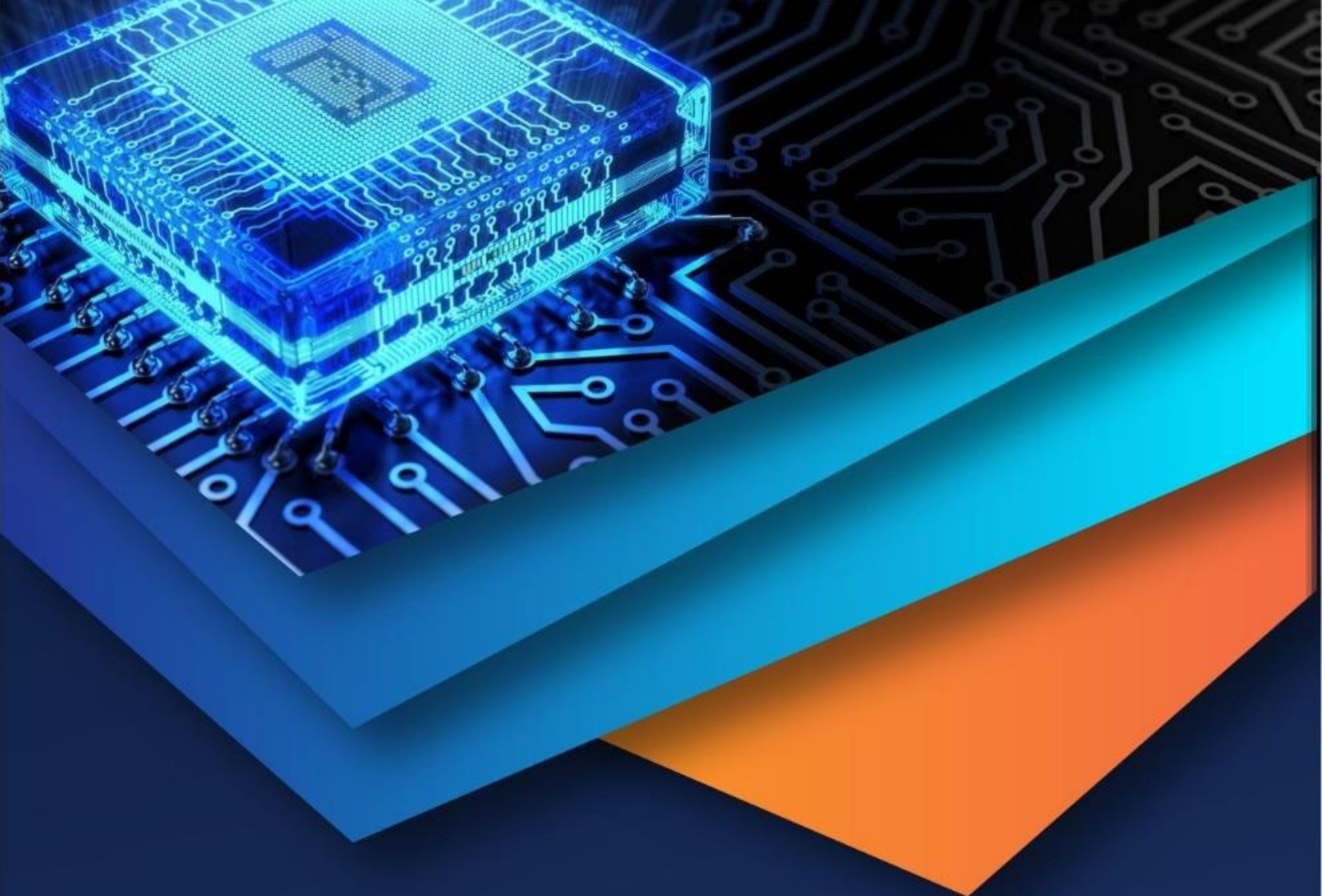

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