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Finite Element Analysis Based Design and Optimization of a Lightweight Electric Vehicle Chassis

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Abstract- The increasing demand for energy-efficient and sustainable transportation has accelerated the development of lightweight electric vehicles. Vehicle weight plays a significant role in determining battery performance, driving range, energy consumption and overall vehicle efficiency. This study focuses on the lightweight design and optimisation of an electric vehicle chassis using advanced structural analysis and lightweight material strategies. The research reviews the application of lightweight materials such as aluminium alloys, magnesium alloys, high-strength steel and composite materials for reducing vehicle mass while maintaining structural strength and safety. Finite Element Analysis (FEA) and topology optimisation techniques are studied to improve chassis stiffness, load distribution and durability, and the relationship between lightweighting, energy efficiency, sustainability and intelligent chassis technologies is examined. Twelve studies published between 1998 and 2026 are reviewed and organised into three themes covering lightweight materials and design strategies, chassis optimisation and structural analysis, and energy efficiency with intelligent chassis performance. The reviewed evidence is consolidated into comparative tables that map each study to its focus, method, principal finding and limitation, alongside a qualitative comparison of candidate lightweight materials and a summary of the structural analysis methods reported. Five research gaps are identified and mapped to corresponding research directions. The findings indicate that optimised lightweight chassis structures can reduce vehicle weight, improve energy efficiency, enhance battery performance and increase driving stability, contributing toward the development of efficient, safe and sustainable electric vehicle systems.

Keywords- Electric vehicle; lightweight chassis; finite element analysis; topology optimisation; lightweight materials; energy efficiency; structural analysis; sustainability; intelligent chassis; vehicle performance.

I. INTRODUCTION

Electric vehicles have become one of the most important solutions for reducing environmental pollution, fossil fuel consumption and greenhouse gas emissions. The rapid growth of the automotive industry and increasing concerns regarding climate change have encouraged researchers and manufacturers to develop sustainable transportation systems. Among the various factors affecting electric vehicle performance, vehicle weight is considered one of the most critical parameters because it directly influences battery efficiency, driving range, acceleration and energy consumption.

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Lightweight vehicle design has therefore emerged as an essential research area in modern electric vehicle development. Reducing vehicle mass decreases power demand and improves overall operational efficiency. However, lightweighting must be achieved without compromising structural strength, passenger safety, durability and vehicle stability. To achieve these objectives, researchers have focused on advanced lightweight materials such as aluminium alloys, magnesium alloys, high-strength steel and carbon fibre composites.

The chassis is one of the most important structural components in an electric vehicle because it supports the vehicle body, battery pack, suspension system, motor and passengers. A lightweight and optimised chassis can improve load distribution, reduce stress concentration and enhance overall vehicle dynamics. Modern design approaches such as Finite Element Analysis (FEA) and topology optimisation are widely used to analyse chassis behaviour and remove unnecessary material from low-stress regions while maintaining structural integrity.

In addition to structural optimisation, intelligent chassis systems and integrated control technologies have improved ride comfort, handling stability and energy management in electric vehicles. Lightweight chassis systems combined with advanced control mechanisms contribute to better vehicle performance and sustainability.

1. Objectives and Contributions of this Study

The main objective of this study is to investigate lightweight electric vehicle chassis design and optimisation methods with emphasis on lightweight materials, structural analysis, energy efficiency and intelligent chassis technologies, and to identify effective approaches for reducing vehicle weight while maintaining safety, durability and performance. The study makes four contributions. First, it consolidates twelve studies into a structured thematic review supported by comparative tables rather than narrative description alone. Second, it compares the candidate lightweight materials on the design criteria that govern their selection, so that material choice rests on stated trade-offs rather than on weight reduction alone. Third, it summarises the structural analysis and optimisation methods reported across the corpus and states what each contributes to the design process. Fourth, it identifies five research gaps and maps each explicitly to a corresponding research direction.

2. Organisation of the Paper

Section 2 reviews the literature across three themes and consolidates it in comparative tables. Section 3 sets out the identified research gaps. Section 4 concludes, and Section 5 details future work.

II. LITERATURE REVIEW

1. Lightweight Materials and Design Strategies in Electric Vehicles

Lightweight design is an important area in electric vehicle development because vehicle mass directly affects energy consumption, driving range, acceleration and overall performance. Song et al. (2022) demonstrated through the lightweight design and testing of an electric experimental car that reducing vehicle weight lowers the load on the battery and improves efficiency. Tezcan (2023) showed that lightweight electric vehicle design can be achieved through proper structural planning, material selection and component optimisation in the context of racing vehicle development.

Lightweight materials such as aluminium alloys, magnesium alloys, high-strength steel and composite materials are widely used to reduce vehicle mass while maintaining strength and safety. Dikkar and Sawant (2026) reported that these materials offer better strength-to-weight ratios than conventional materials, making them suitable for electric vehicle chassis and body structures. Marshall, Nichols and Kirk (1998) showed that lightweight cockpit components and vehicle interior structures also contribute to overall mass reduction without affecting passenger comfort and safety, indicating that lightweighting is a whole-vehicle strategy rather than a chassis-only one.

Research on lightweight electric vehicle design also highlights the importance of balancing weight reduction with manufacturability, cost, durability and structural reliability. Kumanan, Varadarajan and Narayanan (2021), reviewing design strategies across patents and publications, concluded that an effective lightweight strategy requires the combined use of advanced materials, optimised structures and practical manufacturing methods. Dikkar and Sawant (2026) noted that although advanced composites provide excellent lightweight performance, their high cost and complex manufacturing process remain major limitations. The trade-off is therefore central rather than incidental: the material with the best strength-to-weight performance is not necessarily the material a given design should select.

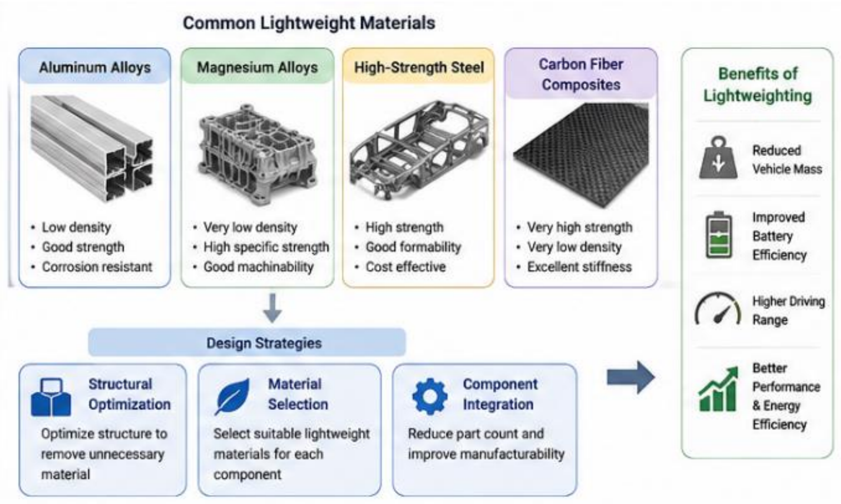

Figure 1: Lightweight materials and design strategies for electric vehicles

Figure 1 illustrates the commonly used lightweight materials in electric vehicle construction, including aluminium alloys, magnesium alloys, high-strength steel and carbon fibre composites. It also shows the relationship between lightweight material selection, vehicle mass reduction, improved battery efficiency and increased driving range, highlighting how lightweight design strategies contribute to better vehicle performance and energy efficiency.

2. Chassis Optimisation and Structural Analysis

The chassis is one of the most important components of an electric vehicle because it supports the vehicle body, battery system, motor, suspension and passenger load. A well-designed chassis must provide sufficient strength, stiffness and safety while keeping total weight as low as possible. Yang et al. (2018) applied finite element analysis to an electric bus frame to study chassis behaviour under different loading conditions and to identify areas where material could be reduced without weakening the structure.

Topology optimisation is another useful method for developing lightweight chassis structures. Scurtu and Moldovanu (2024) applied topology optimisation to the conceptual design of an electric vehicle chassis, removing unnecessary material from low-stress regions while maintaining structural stiffness and load-carrying capacity, and produced designs with improved strength-to-weight performance. The distinction between the two methods matters for design practice: finite element analysis evaluates a proposed geometry, whereas topology optimisation generates one, so the two are complementary stages rather than alternatives.

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Biancolini, Renzi and Rizzoni (2007) showed in the context of a land speed record vehicle that advanced structural analysis and lightweight chassis design can improve speed, stability and overall vehicle performance. The literature indicates that chassis optimisation relates not only to weight reduction but also to vehicle safety and dynamic performance, since an optimised chassis improves load distribution, reduces stress concentration and enhances structural durability. Structural analysis tools are therefore essential in designing lightweight and reliable electric vehicle chassis systems.

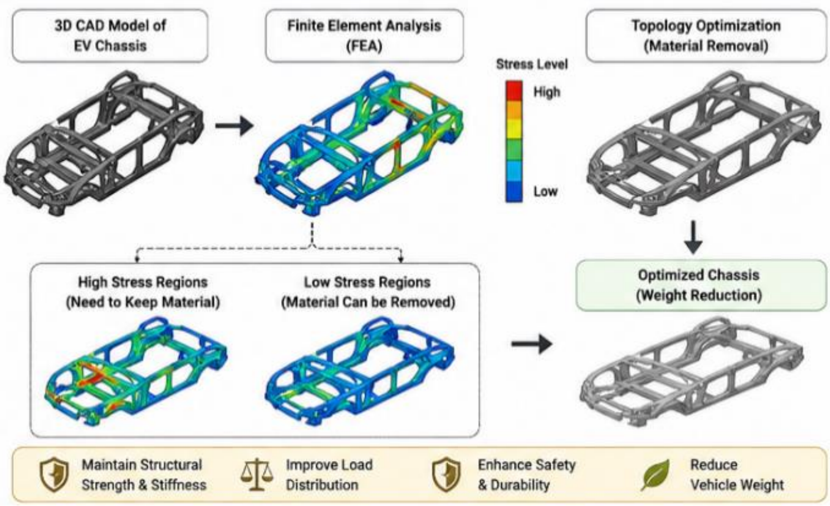

Figure 2: Chassis optimisation and structural analysis in electric vehicles

Figure 2 presents the optimised chassis structure of an electric vehicle developed using finite element analysis and topology optimisation techniques. It identifies high-stress and low-stress regions in the chassis frame and demonstrates how unnecessary material is removed to reduce weight while maintaining structural strength and stiffness, explaining the role of structural analysis in improving safety, load distribution and durability.

3. Energy Efficiency, Sustainability and Intelligent Chassis Performance

Lightweighting has a direct effect on electric vehicle energy efficiency. Choi, Cha and Song (2025) demonstrated through real-world testing and simulation that a lighter vehicle requires less energy during acceleration and operation, particularly in urban driving conditions where frequent stopping and starting occur, and that reducing vehicle mass significantly lowers energy consumption and improves driving range. Theirs is the only study in the corpus to validate lightweighting benefits against real driving data rather than simulation alone.

From a sustainability perspective, Ahmadzadeh et al. (2025) conducted a life cycle assessment of lightweighting and battery technologies and found that lower vehicle mass reduces energy demand during operation and can contribute to reduced emissions associated with electricity consumption and battery usage. They also showed that the environmental benefits of lightweighting depend on the materials used, manufacturing processes and battery technologies, which means life cycle assessment is necessary to establish whether a lightweight design is genuinely more sustainable rather than merely lighter.

Recent developments in intelligent chassis systems have further improved electric vehicle performance. Ma et al. (2025) investigated intelligent chassis smoothness and reported improvements in ride comfort, handling stability and energy management. Fan et al. (2025) reviewed integrated control technologies for four in-wheel motor drive chassis and showed that such systems provide better chassis control, improving vehicle stability and efficiency. The literature indicates that combining lightweight design with intelligent chassis control can improve electric vehicle performance, comfort, safety and sustainability.

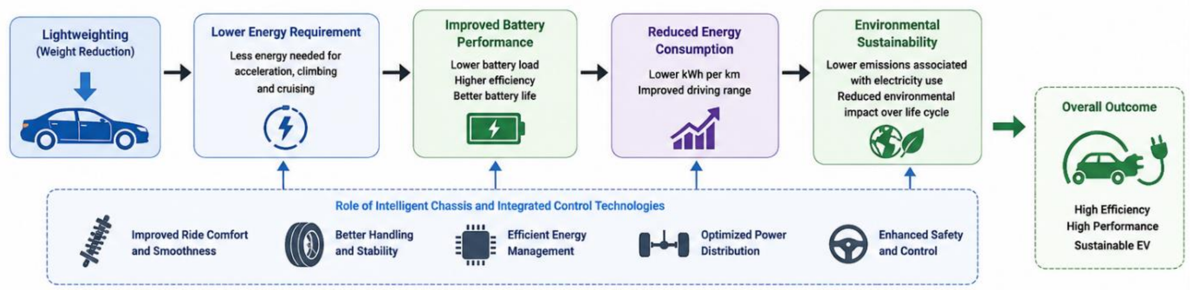

Figure 3: Effect of lightweighting on energy efficiency and sustainability

Figure 3 shows the relationship between vehicle weight reduction, energy consumption, battery performance and environmental sustainability in electric vehicles. The diagram illustrates that lightweight vehicles require less propulsion energy, resulting in lower battery usage and reduced environmental impact, and demonstrates how intelligent chassis systems and integrated control technologies improve ride stability, energy management and overall vehicle efficiency.

4. Consolidated Summary of the Reviewed Literature

Table 1 organises the reviewed studies by theme, and Table 2 compares each study on research focus, method, principal finding and the limitation it leaves unresolved. The limitation column reflects the assessment of this study rather than statements made by the original authors.

Table 1: Thematic organisation of the reviewed literature

Theme	Analytical focus	Studies	Count
T1. Lightweight materials and design strategies	Material selection, strength-to-weight performance, component-level lightweighting and design strategy	Song et al. (2022); Tezcan (2023); Dikkar & Sawant (2026); Kumanan et al. (2021); Marshall et al. (1998)	5
T2. Chassis optimisation and structural analysis	Finite element analysis, topology optimisation and structural performance evaluation	Yang et al. (2018); Scurtu & Moldovanu (2024); Biancolini et al. (2007)	3
T3. Energy efficiency, sustainability and intelligent chassis	Energy consumption, life cycle assessment, chassis smoothness and integrated control	Choi et al. (2025); Ahmadzadeh et al. (2025); Ma et al. (2025); Fan et al. (2025)	4

Table 2: Comparative summary of the reviewed studies

Study	Research focus	Method	Principal reported finding	Limitation for integrated chassis design
Song et al. (2022)	Electric experimental car	Lightweight design with physical testing	Weight reduction lowers battery load and improves efficiency	Experimental vehicle; findings not generalised to production designs
Tezcan (2023)	Racing electric vehicle	Design and manufacturing analysis	Structural planning and material selection reduce mass effectively	Racing context; cost and comfort constraints differ from road vehicles
Dikkar & Sawant (2026)	Lightweight materials	Review of material properties and applications	Advanced materials offer superior strength-to-weight ratios	Composite cost and manufacturing complexity noted but not quantified

Study	Research focus	Method	Principal reported finding	Limitation for integrated chassis design
Kumanan et al. (2021)	Lightweighting design strategies	Review of patents and publications	Effective strategy requires materials, structure and manufacturing together	Synthesis only; no design case evaluated
Marshall et al. (1998)	Cockpit and interior components	Component development study	Interior lightweighting contributes to mass reduction	Earliest study in the corpus; predates current EV architectures
Yang et al. (2018)	Electric bus frame	Finite element analysis	FEA identifies where material can be reduced safely	Bus frame geometry; load cases differ from passenger EVs
Scurtu & Moldovanu (2024)	Chassis conceptual design	Topology optimisation	Material removal from low-stress regions improves strength-to-weight	Conceptual stage; manufacturability of optimised geometry untested
Biancolini et al. (2007)	Land speed record vehicle	Structural analysis and lightweight design	Structural analysis improves speed, stability and performance	Extreme-performance context; limited transferability to urban EVs
Choi et al. (2025)	Energy consumption	Real-world testing with simulation	Mass reduction significantly lowers consumption and extends range	Focuses on energy outcome rather than structural design method
Ahmadzadeh et al. (2025)	Sustainability of lightweighting	Comprehensive life cycle assessment	Environmental benefit depends on material and battery technology	Assessment-level; provides no design or optimisation procedure
Ma et al. (2025)	Intelligent chassis smoothness	Investigation of chassis dynamics	Intelligent chassis improves comfort, stability and energy management	Control-oriented; structural mass not addressed
Fan et al. (2025)	In-wheel motor drive chassis	Review of integrated control technologies	Integrated control improves chassis stability and efficiency	Review of control systems; not linked to structural optimisation

Three observations follow from Table 2. First, the corpus divides cleanly between studies that address structure and studies that address control, and no reviewed study treats the two together, which is the integration this work proposes. Second, only Choi et al. (2025) and Song et al. (2022) report physical testing; the remaining structural work is simulation-based or conceptual, so the experimental validation gap identified in Section 3 is evidenced by the corpus itself. Third, the studies span 1998 to 2026 and differ widely in vehicle class, from land speed record vehicles and racing cars to buses and experimental cars, so findings must be read with the load case and duty cycle of each vehicle class in mind rather than transferred directly.

5. Comparison of Candidate Lightweight Materials

Table 3 compares the material classes discussed across the corpus on the criteria that govern selection in practice. The comparison is qualitative and reflects the relative positions reported in the reviewed studies rather than measured property values, which the corpus does not report on a common basis.

Table 3: Qualitative comparison of candidate lightweight chassis materials

Material class	Weight reduction potential	Structural strength	Cost and manufacturability	Design considerations reported
High-strength steel	Modest relative to alternatives	High and well characterised	Lowest cost; established manufacturing	Familiar joining and forming processes; conservative choice where cost dominates
Aluminium alloys	Substantial	Good strength-to-weight ratio	Moderate cost; established in automotive use	Widely applied to chassis and body structures
Magnesium alloys	High	Good strength-to-weight ratio	Higher cost; more demanding processing	Attractive on mass grounds; processing constraints govern application
Carbon fibre and composites	Highest reported	Excellent strength-to-weight ratio	High cost; complex manufacturing process	Best lightweight performance but cost and process complexity are the stated limiting factors

The table makes the central selection tension explicit: weight reduction potential and cost move in opposite directions across the material classes, so the material offering the greatest mass saving is rarely the material a cost-constrained design can adopt. This is why the corpus consistently recommends combining material selection with structural optimisation rather than relying on material substitution alone.

6. Structural Analysis and Optimisation Methods

Table 4 summarises the structural analysis and optimisation methods reported across the corpus, stating what each contributes to the design process and where it applies.

Table 4: Structural analysis and optimisation methods reported in the reviewed literature

Method	Contribution to the design process	Design stage	Reported in
Finite element analysis	Evaluating stress, stiffness and deformation of a proposed chassis geometry under defined load cases	Evaluation of an existing design	Yang et al. (2018); Biancolini et al. (2007)
Topology optimisation	Generating a material layout by removing material from low-stress regions subject to stiffness constraints	Concept generation	Scurtu & Moldovanu (2024)
Material selection analysis	Choosing material class against strength, mass, cost and manufacturability criteria	Concept and detail design	Dikkar & Sawant (2026); Kumanan et al. (2021)
Physical prototype testing	Verifying predicted structural and energy behaviour on a built vehicle	Validation	Song et al. (2022); Choi et al. (2025)
Life cycle assessment	Evaluating environmental impact across material production, use and end of life	Sustainability evaluation	Ahmadzadeh et al. (2025)
Integrated chassis control analysis	Assessing dynamic behaviour, ride comfort and stability of the controlled vehicle	System-level performance	Ma et al. (2025); Fan et al. (2025)

The table shows that the corpus covers concept generation and evaluation well but is thin at the validation stage, with only two studies reporting physical testing. It also shows that structural methods and control analysis are applied by different groups of studies, reinforcing the integration gap identified below.

III. RESEARCH GAP

Previous studies have extensively addressed lightweight materials, chassis optimisation techniques and energy efficiency improvement in electric vehicles. Aluminium alloys, magnesium alloys, composite materials and high-strength steel have been investigated for reducing vehicle weight while maintaining structural safety, and finite element analysis and topology optimisation have been widely applied to improve chassis strength and reduce unnecessary material usage. Despite this progress, five research gaps remain. They are stated below and mapped to corresponding research directions in Table 5.

First, many studies concentrate on individual aspects such as material selection, structural analysis or energy efficiency separately rather than integrating them within a single design process, which limits the ability to evaluate design trade-offs across criteria.

Second, limited research has integrated lightweight chassis optimisation with intelligent chassis control systems to evaluate their combined influence on vehicle stability, ride comfort and energy management. As Table 2 shows, structural studies and control studies form largely separate groups within the literature.

Third, most existing studies focus on passenger cars and racing vehicles, while fewer address lightweight chassis development for compact experimental electric vehicles and low-cost applications, where cost and manufacturability constraints are considerably tighter.

Fourth, there is a lack of real-time performance validation under different driving conditions. Many studies rely heavily on simulation and theoretical analysis, with limited experimental verification of lightweight chassis behaviour in practical operating environments.

Finally, the environmental impact and sustainability of lightweight materials are often discussed generally, while detailed comparative studies on cost, recyclability and manufacturing feasibility remain limited.

There is therefore a need for further research on the integrated design and optimisation of lightweight electric vehicle chassis systems combining structural efficiency, intelligent control technologies, practical manufacturability and sustainability considerations. The present study aims to address these gaps by developing and analysing a lightweight electric vehicle chassis with improved structural performance, reduced weight and enhanced energy efficiency.

Table 5: Research gaps mapped to corresponding research directions

No.	Identified research gap	Corresponding research direction
G1	Material, structural and energy aspects studied separately	Multi-objective optimisation treating mass, stiffness, cost, manufacturability and sustainability jointly
G2	Structural optimisation not integrated with intelligent chassis control	Coupled evaluation of optimised structures with integrated control systems for stability and energy management

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No.	Identified research gap	Corresponding research direction
G3	Compact and low-cost electric vehicles under-represented	Chassis design studies targeted at compact, low-cost and urban electric vehicles
G4	Limited experimental validation under real driving conditions	Physical prototype testing covering structural behaviour, vibration, crash performance and durability
G5	Sustainability of lightweight materials discussed generally	Comparative studies of cost, recyclability, manufacturing feasibility and life cycle impact across material classes

IV. CONCLUSION

This study reviewed the importance of lightweight design and chassis optimisation in electric vehicles. The literature indicates that lightweight vehicle structures significantly improve energy efficiency, battery performance, driving range and overall vehicle dynamics. Advanced lightweight materials such as aluminium alloys, magnesium alloys, high-strength steel and composite materials play a major role in reducing vehicle mass while maintaining structural strength and safety.

The study also highlighted the importance of finite element analysis and topology optimisation in developing lightweight and structurally efficient chassis systems. These methods identify high-stress and low-stress regions, allowing designers to reduce unnecessary material while preserving stiffness and durability. Distinguishing their roles matters in practice, since finite element analysis evaluates a proposed geometry while topology optimisation generates one, making them complementary stages rather than competing methods. Intelligent chassis technologies and integrated control systems further improve ride comfort, handling stability and energy management.

Three observations emerged from the comparative synthesis. The corpus divides between studies addressing structure and studies addressing control, with none treating the two together. Only two reviewed studies report physical testing, so the experimental validation gap is evidenced by the literature itself. And comparing the material classes on common criteria showed that weight reduction potential and cost move in opposite directions, which is why material substitution alone is insufficient and structural optimisation is required alongside it.

Overall, the research confirms that combining lightweight materials, optimised chassis structures and intelligent control technologies can contribute to the development of efficient, reliable and sustainable electric vehicles. Lightweight chassis optimisation is therefore an essential approach for improving the future performance and sustainability of electric mobility systems.

Future Work

Future research can extend this study in several directions, presented here in order of priority. First, and most immediately, experimental validation of lightweight chassis designs under real driving conditions should be undertaken, using advanced testing methods to evaluate structural behaviour, vibration characteristics, crash performance and durability of optimised chassis systems. This addresses the gap most clearly evidenced by the corpus itself.

Second, multi-objective optimisation techniques should be applied that simultaneously consider weight reduction, structural safety, cost efficiency, manufacturability and environmental sustainability, so that the trade-offs identified in this review are resolved within a single design procedure rather than sequentially.

Third, the integration of intelligent and smart control systems with lightweight chassis structures should be evaluated, assessing the combined effect on vehicle stability, ride comfort and energy management rather than treating structure and control as separate design problems.

Fourth, advanced composite materials and hybrid material combinations should be investigated to achieve greater weight reduction at lower manufacturing cost, with the cost and process constraints reported quantitatively rather than noted qualitatively.

Fifth, sustainability assessment of lightweight materials should be extended to cover recyclability, manufacturing impact and life cycle cost analysis on a comparative basis across material classes.

Finally, lightweight chassis development should be pursued for compact, low-cost and high-performance electric vehicles suitable for urban transportation applications, where the design constraints differ materially from the passenger car and racing contexts that dominate the current literature.

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