3.1 Introduction

In the contemporary era of technological advancements, the automotive industry is undergoing a pivotal transition, gravitating towards sustainable and eco-friendly transportation solutions. This transition is primarily driven by the escalating concerns over environmental degradation, fossil fuel depletion, and the consequential need for renewable energy sources. Electric vehicles (EVs), emerging as a cornerstone in this paradigm shift, represent not just an alternative to internal combustion engine vehicles but also a step towards a more sustainable future. The focus of this research is to contribute to this evolving landscape by designing an energy-efficient electric vehicle (EV) with a particular emphasis on the tadpole structure, which is a novel and promising approach in the realm of EV design.[77]

3.2 Importance of Designing Energy-Efficient Electric Vehicles

The significance of developing energy-efficient EVs cannot be overstated. The global urgency to reduce greenhouse gas emissions and mitigate climate change is compelling industries to rethink and innovate. Energy-efficient EVs stand out as a crucial solution in this regard. They offer the potential to significantly reduce the carbon footprint associated with transportation, a sector that is one of the largest contributors to global CO2 emissions. By enhancing energy efficiency, these vehicles not only promise a reduced environmental impact but also offer improved performance, longer range, and lower operating costs, making them more appealing to consumers and more viable as a long-term sustainable transportation solution.[78]

3.3 Rationale Behind Focusing on the Tadpole Structure

The tadpole structure, characterized by two wheels at the front and one at the rear, presents a unique design opportunity in the realm of EVs. This research is motivated by the potential advantages of the tadpole configuration, such as improved aerodynamics, enhanced stability, and reduced material usage, which collectively contribute to greater energy efficiency. The choice of this structure is also driven by its novelty and the relatively unexplored nature in the field of EV design, offering a fertile ground for innovation and discovery. The tadpole design potentially allows for a more balanced weight distribution and a lower center of gravity, which are crucial for the safety and performance of EVs.[79]

3.4 Outline of the Methodology

The term "methodology" refers to a system of methods, principles, and rules used in a particular discipline or field of study. It encompasses the theoretical underpinnings of the methods and techniques used to conduct research or carry out a project. In essence, methodology provides a blueprint or guideline for how to approach and solve specific problems or answer questions within that discipline.

In this research generalized methodology is used as follows shown in Figure 19. Detailed descriptions and processes used are elaborated in the lateral part of this chapter.

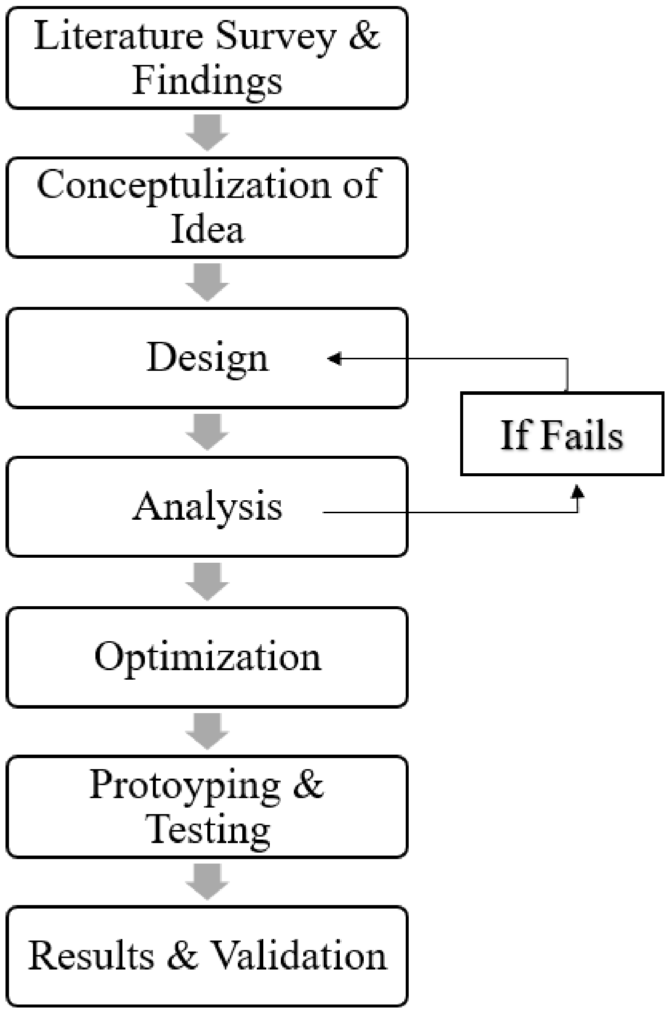

Fig. 19 : Flow Chart of General Methodology Used for Research

This methodology chapter is structured to provide a comprehensive overview of the research process undertaken to design the tadpole-structured EV. It begins with a detailed literature review, establishing the theoretical foundation for the research. This is followed by the initial conceptualization phase, where key requirements for an energy-efficient EV are identified and elaborated upon. The chapter then delves into the design development process, detailing the approach for establishing design parameters, material selection, and the iterative design process. Subsequent chapters cover the simulation and analysis phase, integrating autonomous technology, prototyping, and testing. Finally, the chapter discusses the data collection and empirical analysis, addressing design constraints, and outlines the challenges and limitations encountered during the research. This structured approach ensures a meticulous and holistic development of the energy-efficient tadpole-structured EV.

3.5 Research Design and Approach

3.5.1 Research Design

The methodology adopted for this research is a mixed-methods approach, combining both qualitative and quantitative elements. This multifaceted strategy is crucial for a comprehensive understanding and development of an energy-efficient electric vehicle (EV) with a tadpole structure. The qualitative aspect involves a thorough literature review and conceptual development, providing a deeper understanding of the theoretical underpinnings and design considerations. The quantitative component encompasses the empirical testing and data analysis, offering measurable and statistically significant insights into the performance and efficiency of the design.

3.5.2 Justification for Research Design Choice

The choice of a mixed-methods approach is predicated on the multifaceted nature of vehicle design, which necessitates a balance between theoretical knowledge and empirical validation. Qualitative methods enable a nuanced understanding of complex design concepts and industry trends, while quantitative methods provide hard data for validating hypotheses and design choices. This combination ensures that the research is grounded in solid theoretical foundations while also being rigorously tested and validated through empirical means.

3.6 Literature Review

The literature review forms the backbone of the research, setting the stage for the entire project. It serves to contextualize the research within the current state of knowledge, identify gaps in the existing literature, and guide the subsequent phases of the research. Sources for the literature review include academic journals, industry reports, white papers, and publications from leading automotive and environmental organizations. These sources are meticulously chosen to ensure a comprehensive understanding of the latest advancements and challenges in EV technology, especially focusing on energy efficiency and tadpole structures. The literature is selected based on relevance to the research topic, credibility of the source, and the recency of the publication. Priority is given to peer-reviewed articles and publications from recognized experts in the field.

3.7 Initial Conceptualization

The initial conceptualization phase is where the foundational ideas for the EV design are formulated. This stage involves:

3.7.1 Defining Design Parameters

Key parameters such as vehicle size, weight distribution, aerodynamic profile, and powertrain configuration are established. These parameters are influenced by factors like intended vehicle use, target market, and regulatory standards.

3.7.2 Initial Conceptualization

In this stage from the literature and current industrial scenarios, the primary requirements for an energy-efficient structure for EVs are identified. Also, the parameters affecting performance and majorly affecting the design are considered. Also, Analyzed existing data and regulations to establish performance and efficiency benchmarks to conceptualize the tadpole structure.

3.7.3 Design Approach: Creating an Energy-Efficient EV Structure

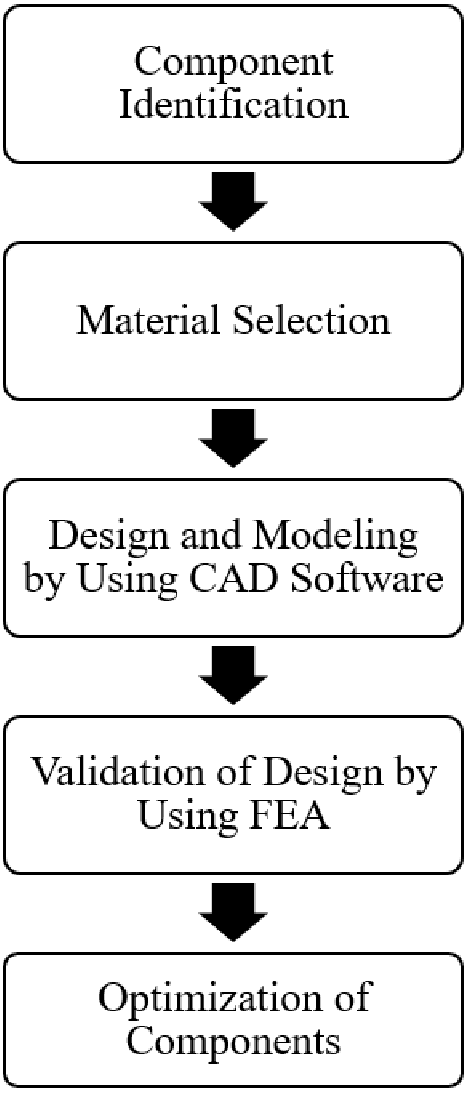

Fig. 20 : Design Approach

3.8 Material Selection

Material selection is a critical decision in this phase, impacting the vehicle's weight, durability, and cost. Factors considered include strength-to-weight ratio, environmental impact, cost, and availability. Materials like lightweight alloys, composites, and recyclable materials are evaluated for their suitability.

3.8.1 Material Selection Criteria

Criteria for material selection are established based on the vehicle's performance requirements, manufacturing capabilities, and sustainability goals. Trade-offs between different materials are carefully evaluated to find the optimal balance.

3.9 Design Development

The design development phase is an iterative process involving constant refinement of the vehicle design. This phase includes:

3.9.1 Establishing Design Parameters

Detailed specifications for each component of the vehicle are developed. This includes the chassis design, motor type, battery capacity, and suspension system. Simulation tools are used to predict the performance and identify potential areas for improvement.

3.9.2 Iterative Design Process

The design undergoes several iterations, each influenced by feedback from simulations, prototype testing, and expert reviews. This iterative process ensures that the final design is not only theoretically sound but also practically viable.

This comprehensive research design and approach ensure that the development of the energy-efficient EV is robust, well-founded, and aligns with both current technological capabilities and future advancements in the field. The mixed-methods approach provides the flexibility and depth needed to explore the complex and evolving landscape of electric vehicle technology.[80]

3.10 Research Design and Approach

The research adopts a mixed-methods approach, integrating qualitative and quantitative elements.

- Qualitative aspect: In-depth literature review and conceptual development.
- Quantitative component: Empirical testing and data analysis.

The research design and approach encompass various methodologies to comprehensively assess and optimize the performance of the electric vehicle. Weight, Camber, and Tire Width Analysis: The research heavily focuses on understanding how the weight of the vehicle, camber (wheel alignment), and tire width impact the vehicle's range and efficiency. This involves both Taguchi and regression analyses to determine the most influential factors and their optimal levels.

3.11 Simulation and Analysis

In the realm of modern vehicle design, especially for electric vehicles (EVs) with specific structures like the tadpole, simulation and analysis play a pivotal role. They provide a means to test, refine, and validate various aspects of the vehicle design before physical prototyping. This section delves into the simulation tools and software utilized, the process and objectives of Finite Element Analysis (FEA), Vehicle Dynamics Simulation, and Suspension and Stability Analysis.[81], [82]

3.11.1 Simulation Tools and Software Used

For this research, a suite of advanced simulation tools and software was employed, each selected for its specific capabilities in analyzing different aspects of the EV design:

- **FEA Software**: Industry-standard FEA software such as ANSYS was used for structural analysis. These tool is renowned for their robustness in handling complex material behaviors and geometries.
- **Vehicle Dynamics Simulation Software**: Tools like MATLAB Simulink and ADAMS CAR provided dynamic simulation capabilities. They are instrumental in modeling and simulating the behavior of the vehicle under various driving conditions.
- **Suspension Analysis Software**: Software such as Lotus Suspension Analysis (Shark) was used for detailed suspension modeling and analysis.

3.11.2 Process of Finite Element Analysis

The primary objective of FEA in this research was to assess the structural integrity, durability, and safety of the EV chassis and components, particularly focusing on the unique demands of the tadpole structure. FEA aimed to predict how the design would respond to various physical stresses and strains, thus ensuring its reliability and safety.

The FEA setup involved creating detailed 3D models of the EV's chassis and critical components. These models were constructed based on the design parameters established in the conceptualization phase. Material properties, including elasticity, density, and thermal characteristics, were input based on the selected materials.[83]

3.11.3 Expected Outcomes

- Identification of stress concentration areas.
- Analysis of deformation under load conditions.
- Fatigue analysis to predict the lifespan of components.
- Safety factor calculations to ensure compliance with industry standards.

3.11.4 Vehicle Dynamics Simulation

- **Parameters Considered:** Several key parameters were considered in the vehicle dynamics simulation:
- **Weight Distribution**: Critical for understanding the impact of the vehicle's center of gravity on handling and stability.
- **Aerodynamic Drag**: Including drag and lift, which directly affect energy efficiency and high-speed stability.
- **Suspension Settings**: Such as spring rates, damping coefficients, and camber angles, which influence ride quality and handling.
- **Tire Characteristics**: Including tire grip and wear patterns, which affect the vehicle's traction and cornering abilities.

3.11.5 Relevance to the Study

Understanding these parameters was crucial for designing an EV that balances efficiency, safety, and performance. For instance, optimizing aerodynamics could significantly reduce energy consumption, while precise suspension tuning could enhance passenger comfort and handling stability.

3.11.6 Suspension and Stability Analysis

Suspension and stability analysis utilized both computational tools and physical testing methods. The computational analysis involved simulating various suspension configurations to determine the optimal setup. The tools provided insights into parameters like roll stiffness, damping ratios, and spring rates. Physical testing methods included skid pad tests and slalom courses to validate the simulation results and further refine the suspension design.[84]

Suspension and stability are crucial for any vehicle, but they are particularly vital in the context of a tadpole-structured EV. The unique configuration of this structure demands a bespoke approach to suspension design to ensure vehicle stability, especially during cornering and under different load conditions. Properly designed suspension systems not only contribute to the vehicle's overall performance but also play a significant role in ensuring passenger comfort and safety.[85]

The simulation and analysis phase of this research was integral in shaping the final EV design. By employing advanced tools and methodologies for Finite Element

Analysis, Vehicle Dynamics Simulation, and Suspension and Stability Analysis, the research was able to iteratively refine and validate the design, ensuring that the final product was not only innovative in its approach but also robust, safe, and efficient. These simulations bridged the gap between theoretical design and practical application, allowing for a comprehensive understanding and optimization of the tadpole-structured EV.[86]

3.12 Prototyping and Testing

Prototyping and testing constitute a critical phase in the development of an energy-efficient electric vehicle (EV) with a tadpole structure. This stage transitions the theoretical and simulated designs into a tangible form, allowing for real-world testing and evaluation. This process not only tests the feasibility of the design but also ensures that the final product meets all performance, safety, and efficiency standards.

3.12.1 Process of Physical Prototyping

- **Design Considerations:** The prototyping phase commenced with a thorough review of the design specifications derived from the conceptualization and simulation stages. Key considerations included:
- **Ergonomics and Aesthetics**: Ensuring the prototype is user-friendly and visually appealing.
- **Functional Requirements**: Adherence to the performance parameters established during the design phase.

3.12.2 Manufacturing Techniques

Advanced manufacturing techniques were employed to construct the prototype:

- **CNC Machining**: For precise fabrication of metal components.
- **3D Printing**: For complex shapes and rapid prototyping of certain parts.
- **Composite Molding**: For producing lightweight and strong body panels.

3.13 Description of Various Tests

Below tests assess the vehicle's handling dynamics and performance which can be tested for various parameters.

- **Slalom Testing**: Evaluating the vehicle’s maneuverability and responsiveness.
- **Brake Test**: Included stopping distance and high-speed braking tests.
- **Aerodynamic Drag Test**: Evaluated the vehicle's efficiency at higher speeds.

- **Yaw Rate Testing**: Assessed the vehicle's response to steering inputs.
- **Pitch Testing**: Evaluated the vehicle's response to acceleration and braking.
- **Rollover Testing**: Assessed the vehicle's susceptibility to rollover under various conditions.
- **Center of Gravity Testing**: Determined the vehicle's stability and handling characteristics.
- **Lateral Force Testing**: Evaluated the vehicle's handling characteristics under lateral loads.
- **Acceleration and Speed Test**: Measured the vehicle's acceleration capability and top speed.
- **Range Test**: Assessed the vehicle's fuel efficiency and overall range.

3.14 Methodology of Testing

Each test was designed to replicate real-world conditions as closely as possible. Scenarios were set up based on typical usage patterns, legal standards, and safety considerations.

3.14.1 Data Collection and Analysis

Data collection employed a combination of onboard sensors, high-speed cameras, GPS tracking, and telemetry systems to gather comprehensive performance data.

Data analysis involved both quantitative and qualitative methods. Quantitative data from sensors and telemetry provided objective performance metrics, while qualitative observations helped in understanding real-world dynamics and user experience.

Feedback from each testing phase was meticulously analyzed and used to refine the prototype. Key areas of focus included:

- **Design Modifications**: Alterations in design were made based on test outcomes. For instance, aerodynamic features might be tweaked to reduce drag, or suspension settings adjusted to improve handling.
- **Material Reevaluation**: In some cases, testing may reveal the need for different materials or construction techniques.
- **Performance Enhancement**: Based on test data, improvements in various systems like braking, steering, and motor efficiency were implemented.

Testing also provided insights into potential user experience enhancements and maintenance requirements, ensuring the final product is not only safe and efficient but also user-friendly and practical for everyday use.

The prototyping and testing phase was pivotal in bridging the gap between theoretical design and practical application. Through rigorous testing and iterative improvements, this phase ensured that the final EV design was optimized for performance, safety, and efficiency, validating the vehicle's readiness for real-world application. This process exemplifies the importance of empirical validation in the development of innovative automotive technologies, particularly in the context of EVs with unconventional structures like the tadpole design.

3.14.2 Data Collection and Empirical Analysis

In the journey of developing an energy-efficient electric vehicle (EV) with a tadpole structure, empirical data collection and analysis play a crucial role. This phase involves gathering real-world data on various parameters, analyzing them, and incorporating the findings into the vehicle’s design. This section elaborates on the methods of collecting road condition data, studying real-world driving patterns, and gathering suspension system data, along with the respective analysis techniques and their impacts on design decisions.

3.14.3 Road Condition Data

Road condition data was sourced from various channels to ensure a comprehensive understanding of the different environments the EV would encounter. These sources included:

- **Transportation Departments**: For official records of road types and conditions.
- **Geographic Information Systems (GIS)**: For detailed mapping and terrain data.
- **Field Surveys**: Conducted to gather first-hand information on road conditions.

3.14.4 Data Collection Methods

Data was collected using a combination of methods:

- **Automated Data Collection**: Utilizing GPS and GIS technology to gather large-scale data on road types, gradients, and surface conditions.

- **Manual Surveys**: Conducting physical inspections and assessments of road conditions in targeted areas.
- **Public Databases**: Accessing publicly available data on road conditions, traffic patterns, and historical weather impacts.

3.15 Analysis Techniques

Analysis of road condition data involved:

- **Statistical Analysis**: To identify common road features and conditions.
- **Simulation Modeling**: Using the collected data to simulate different road conditions in vehicle testing simulations.
- **Geospatial Analysis**: To map and understand the geographical distribution of various road types and conditions.

3.15.1 Performance Analysis

Included Taguchi and regression analyses to understand the impact of weight, camber, and tire width on the vehicle's range. Each of these stages plays a critical role in ensuring the final vehicle meets performance, safety, and quality standards. The comprehensive testing regime demonstrates the thoroughness in evaluating and optimizing the vehicle’s design and functionality.

3.16 Additional Considerations

The research also considers aspects like ergonomic and aesthetic design, functional requirements, and compliance with legal standards and safety considerations.

The methodology outlined in the thesis is comprehensive and designed to ensure the development of a robust, efficient, and practical EV with a tadpole structure. The mixed-methods approach, encompassing both theoretical research and practical application, provides a solid foundation for innovative automotive technology development.

In the context of vehicle design and optimization, the Multi-Criteria Decision Making (MCDM) method plays a crucial role. This approach is particularly useful when selecting the optimal solutions for design elements, taking into account a range of factors such as weight, stiffness, and aesthetics. MCDM assists decision-makers in identifying the most suitable option by considering multiple perspectives and preferences.

Here's a more detailed look into how MCDM can be applied in vehicle technology:

1. **Weight Considerations**: In vehicle design, weight is a critical factor, especially for electric vehicles. Lighter vehicles generally have better efficiency and performance. Using MCDM, you can weigh the importance of reducing vehicle weight against other design aspects like structural strength or cost.
2. **Stiffness and Structural Integrity**: The stiffness of components like the chassis, suspension, and body panels is vital for the vehicle's handling, safety, and durability. MCDM helps in balancing stiffness with other factors like material cost and weight.
3. **Aesthetic Appeal**: While technical specifications are crucial, the visual appeal of a vehicle also plays a significant role in consumer acceptance. MCDM can aid in finding a balance between aesthetic appeal and functional design elements.
4. **Application Across Sectors**: MCDM isn't limited to vehicle design. It's widely used in various fields, including engineering, management, economics, and environmental research. This versatility makes it a powerful tool in decision-making where multiple criteria must be considered.

In vehicle technology, particularly for electric and hybrid vehicles, the application of MCDM ensures that the final design is not just focused on a single aspect like range or speed, but is a well-rounded product considering multiple facets of vehicle performance and design. This holistic approach is crucial for creating vehicles that are not only efficient and functional but also meet the broader needs and preferences of consumers and the market.