Supplementary Material

A Design-Oriented Scoping Review of Electric-Vehicle Gearbox Technologies: Architectures, Gear-Ratio Selection, Efficiency, NVH, and Reliability

Semaan Amine, Ossama Mokhiamar, and Eddie Gazo-Hanna

S1. Targeted Supplementary-Search Audit

The 40-source structured search is the reproducible PRISMA-ScR core reported in the main manuscript. The 12-source supplement was a gap-directed, iterative identification step undertaken after the structured screening. Its query families, retained references, gaps addressed, and source-specific inclusion rationales are documented in Table S1. Complete historical query-level hit counts and screening records were not retained, and no retrospective numbers were reconstructed or invented. Accordingly, the supplementary process is transparent and auditable at the query-family and retained-source level, but it is not retrospectively reproducible as a second complete PRISMA stream. For clarity, TSF denotes targeted-search family: TSF-1 covers lubrication, thermal behavior, and speed-dependent losses; TSF-2 covers planetary load sharing and measurement; TSF-3 covers compound planetary and 3K electric-drive systems; and TSF-4 covers durability, fatigue, wear, bearing life, and lubricant degradation.

Table S1. Targeted supplementary-search families and source-level inclusion audit.

TSF code	Query family / refinement	Search route	Retained reference	Gap addressed and inclusion rationale
TSF-1	("electric vehicle" OR "e-axle" OR "electric drive unit") AND (lubrication OR lubricant OR "e-fluid" OR churning OR windage OR "oil splash" OR thermal)	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[16] Kumar et al. (2025)	High-speed oil-splash/churning behavior in an e-axle gearbox; gap in speed-dependent loss evidence.
TSF-1	same targeted-search family TSF-1, refined with power-loss and oil-volume terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[17] Zhang et al. (2024)	Experimental/validated e-axle lubricant and power-loss evidence.
TSF-1	same targeted-search family TSF-1, refined with e-fluid and heat-transfer terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[18] Tung et al. (2020)	Review of e-fluid performance and thermal–lubrication requirements for integrated drives.

TSF code	Query family / refinement	Search route	Retained reference	Gap addressed and inclusion rationale
TSF-1	same targeted-search family TSF-1, refined with integrated thermal-management terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[19] Yashwanth et al. (2024)	Thermal-management evidence for compact electric drive units.
TSF-1	same targeted-search family TSF-1, refined with drive-motor thermal review terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[20] Xu et al. (2023)	Current review of electric-drive thermal-management methods and limitations.
TSF-2	(planetary OR epicyclic) AND ("load sharing" OR "planet load" OR experimental OR prototype OR measurement) AND (gearbox OR transmission)	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[21] Götz et al. (2022)	Experimental dynamic load-sharing evidence and measurement-based planetary mechanics.
TSF-2	same targeted-search family TSF-2, refined with mesh-load coefficient and assembly-deviation terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[22] Boguski et al. (2012)	Experimental/analytical load-sharing evaluation under manufacturing and assembly deviations.
TSF-4	("electric vehicle" OR e-axle OR gearbox) AND ("gear fatigue" OR "bearing life" OR micropitting OR scuffing OR durability OR "thermal cycling")	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[23] Li et al. (2012)	Mixed-EHL/contact-fatigue evidence relevant to durability and lubricant-film adequacy.
TSF-4	same targeted-search family TSF-4, refined with gear bending-fatigue and reliability-level terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[24] Wang et al. (2025)	Experimental gear bending-fatigue limits for reliability-aware sizing.

TSF code	Query family / refinement	Search route	Retained reference	Gap addressed and inclusion rationale
TSF-1/TSF-4	TSF-1 loss/lubricant family combined with TSF-4 durability terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[25] Handschuh & Schragal (2026)	Experimental parallel-axis gear-pair efficiency with automotive fluids; lubricant/surface sensitivity.
TSF-1	same targeted-search family TSF-1, refined with axle thermal mapping terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[26] Xu et al. (2011)	Measured automotive axle temperature field and thermal–lubrication behavior.
TSF-4	same targeted-search family TSF-4, refined with EV grease and lubricant-degradation terms	Narrow database queries plus backward/forward citation chaining; same topical and evidence eligibility rules as the core search.	[27] Shah et al. (2021)	EV/hybrid grease requirements, compatibility, aging, and lubricant-related reliability context.

Note: TSF-3 (compound planetary/3K electric-drive systems) was used during gap checking, but no additional source beyond the retained 52-source set was added solely from that query family. Compound-planetary evidence in the synthesis is therefore explicitly described as limited rather than expanded artificially.

S2. Source-Level Classification Matrix

Table S2 provides the auditable source-level coding used for the descriptive statistics in Figure 2 and the dimension-separated evidence counts in Table 5 of the main manuscript. Ratio count, topology, and integration are coded independently. Multiple technical-focus assignments are permitted. A general/not-specified code is used whenever the source does not support a more specific architecture assignment.

Table S2. Source-level classification matrix for the 52-source synthesis set.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
[1] Sorniotti et al. (2011)	Structured-search core	Original research / SAE journal; Comparative layout selection and simulation	Single-speed; Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Early EV assumptions; limited treatment of NVH, thermal behavior, and durability.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
[2] Spanoudakis et al. (2020)	Structured-search core	Original peer-reviewed research; Gear-ratio selection and drive-cycle energy analysis	Single-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Focused on Single-speed ratio selection; simplified gearbox loss, NVH, and durability treatment.
[3] Lacock et al. (2023)	Structured-search core	Review / secondary synthesis; Review and comparative efficiency analysis	Single-speed; Multi-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency	Level D: Contextual	Broad efficiency focus; limited detailed mechanical design, NVH, and durability modeling.
[4] Gao et al. (2022)	Structured-search core	Review / secondary synthesis; Review of topology optimization and development trends	Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level D: Contextual	Focused mainly on Two-speed systems; limited full architecture comparison.
[5] Jeong et al. (2024)	Structured-search core	Original peer-reviewed research; Structural design and optimization	Two-speed	Planetary	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Limited experimental validation and partial NVH/reliability treatment.
[6] Machado et al. (2021)	Structured-search core	Review / secondary synthesis; Review of technologies and trends	Multi-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency	Level D: Contextual	Strong Multi-speed focus; less emphasis on detailed losses, NVH, thermal behavior, and reliability.
[7] Ahssan et al. (2018)	Structured-search core	Review / SAE journal; Review of performance and complexity	Multi-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency	Level D: Contextual	Limited taxonomy of gear-train topologies and practical mechanical-design constraints.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
[8] Bertucci et al. (2024)	Structured-search core	Original peer-reviewed research; Technical-economic analysis	Single-speed; Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Results depend on cost and usage assumptions; limited NVH and durability analysis.
[9] Huang et al. (2020)	Structured-search core	Original peer-reviewed research; Optimal design and control	Two-speed	Planetary	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Limited experimental validation and incomplete coupled efficiency-NVH-thermal treatment.
[10] Hamrayev et al. (2023)	Structured-search core	Prototype / experimental study; Design and testing	General/not ratio-specific	Compound planetary	Standalone gearbox/transmission	Efficiency; Thermal–lubrication; Reliability/durability; Experimental validation	Level A: Measured/Prototype	Specific 3K concept; broader benchmarking against alternatives remains limited.
[11] Cai et al. (2022)	Structured-search core	Review / secondary synthesis; Critical review	Direct-drive	General/component-level/not specified	In-wheel/distributed drive	Efficiency	Level D: Contextual	Motor-focused; limited gearbox architecture, mechanical loss, and NVH comparison.
[12] Hua et al. (2021)	Structured-search core	Review / secondary synthesis; Review	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	NVH	Level D: Contextual	Broad NVH review; not focused on gearbox architecture selection.
[13] Horvath and Feszty (2025)	Structured-search core	Review / secondary synthesis; Comprehensive review of surface waviness and NVH	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	NVH; Reliability/durability	Level D: Contextual	Gear-NVH focused; limited efficiency, thermal, and architecture-selection scope.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
[14] Sun et al. (2020)	Structured-search core	Review / secondary synthesis; Survey of mesh excitation classification and mitigation	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	NVH	Level D: Contextual	General gear-whine focus; not specific to EV architecture selection.
[15] Hazra and Khan (2025)	Structured-search core	SAE review / contextual; Review	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	NVH	Level D: Contextual	Broad EV NVH scope; limited gearbox-specific architecture and mechanical-design detail.
[16] Kumar et al. (2025)	Targeted supplement	CFD technical paper; CFD churning-loss and oil-splash simulation (VOF)	General/not ratio-specific	General/component-level/not specified	Integrated EDU/e-axle	Efficiency; Thermal–lubrication	Level B: Modeled/Optimized	Simulation-based; single unit; limited experimental and durability validation.
[17] Zhang et al. (2024)	Targeted supplement	Original peer-reviewed research; Power-loss model with test-bench validation	General/not ratio-specific	Planetary	Integrated EDU/e-axle	Efficiency; Thermal–lubrication; Experimental validation	Level A: Measured/Prototype	Light-duty truck e-axle specific; NVH and long-term durability not covered.
[18] Tung et al. (2020)	Targeted supplement	Review / secondary synthesis; Review of lubrication and thermal-management trends	General/not ratio-specific	General/component-level/not specified	Integrated EDU/e-axle	Efficiency; Thermal–lubrication	Level D: Contextual	Broad lubrication/thermal review; not gearbox-architecture specific.
[19] Yashwanth et al. (2024)	Targeted supplement	SAE journal / modeling study; Lumped-	General/not ratio-specific	General/component-level/not specified	Integrated EDU/e-axle	Thermal–lubrication	Level B: Modeled/Optimized	Thermal focus; gearbox NVH and

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
		parameter thermal network with reduced-order modeling						durability not addressed.
[20] Xu et al. (2023)	Targeted supplement	Review / secondary synthesis; Review of thermal-analysis and cooling methods	General/not ratio-specific	General/component-level/not specified	Integrated EDU/e-axle	Thermal–lubrication	Level D: Contextual	Motor-thermal focus; limited gearbox lubrication and load-sharing detail.
[21] Götz et al. (2022)	Targeted supplement	Experimental measurement study; Back-to-back test-rig load-sharing measurement	General/not ratio-specific	Planetary	General/not integration-specific	Reliability/durability; Experimental validation	Level A: Measured/Prototype	Not EV-specific; e-axle thermal/NVH conditions not represented.
[22] Boguski et al. (2012)	Targeted supplement	Experimental method study; New measurement method for planet load sharing and sun orbit	General/not ratio-specific	Planetary	General/not integration-specific	Reliability/durability; Experimental validation	Level A: Measured/Prototype	Foundational method; not an EV e-axle validation.
[23] Li et al. (2012)	Targeted supplement	Original peer-reviewed research; Fatigue model under mixed-EHL conditions	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Thermal–lubrication; Reliability/durability	Level B: Modeled/Optimized	Component-level fatigue model; not EV architecture specific.
[24] Wang et al. (2025)	Targeted supplement	Experimental measurement study; Bending-fatigue staircase	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Reliability/durability; Experimental validation	Level A: Measured/Prototype	Material/fatigue focus; not a full gearbox-architecture study.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
		testing at reliability levels						
[25] Handschuh & Schragal (2026)	Targeted supplement	Experimental measurement study; Parametric mechanical-efficiency testing with automotive fluids	General/not ratio-specific	Parallel-axis	General/not integration-specific	Efficiency; Thermal–lubrication; Experimental validation	Level A: Measured/Prototype	Gear-pair level; system-level e-axle behavior not covered.
[26] Xu et al. (2011)	Targeted supplement	SAE technical paper; Thermal mapping of a drive axle	General/not ratio-specific	General/component-level/not specified	Standalone gearbox/transmission	Efficiency; Thermal–lubrication; Reliability/durability	Level B: Modeled/Optimized	Conventional axle; pre-dates modern compact e-axles.
[27] Shah et al. (2021)	Targeted supplement	Review / secondary synthesis; Review of grease performance requirements	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Thermal–lubrication; Reliability/durability	Level D: Contextual	Lubricant-focused review; no gearbox architecture comparison.
[28] Hofman and Dai (2010)	Structured-search core	Conference paper / model comparison; Energy-efficiency comparison	Single-speed; Two-speed; Multi-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Older vehicle and motor assumptions; limited modern e-axle and NVH treatment.
[29] Kwon et al. (2023)	Structured-search core	Original peer-reviewed research; Optimization including electrical and mechanical efficiency	Multi-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Improved efficiency treatment, but NVH, thermal behavior, and reliability remain simplified.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
[33] Leise et al. (2020)	Structured-search core	Book-chapter / optimization study; Global optimization of gearbox design	General/not ratio-specific	Parallel-axis	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Idealized constraints; limited experimental and NVH/thermal validation.
[39] Ruan et al. (2016)	Structured-search core	Original peer-reviewed research; Energy-consumption and cost comparison	Single-speed; Two-speed; Multi-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency	Level B: Modeled/Optimized	Older assumptions; simplified detailed loss, NVH, and durability modeling.
[40] Gao et al. (2015)	Structured-search core	Original peer-reviewed research; Gear-ratio optimization and shift control	Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Early Two-speed concept; limited detailed NVH, thermal, and durability treatment.
[41] Hofman and Salazar (2020)	Structured-search core	Preprint / contextual; Analytical modeling and optimization	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Ratio design; Efficiency; Optimization/control	Level D: Contextual	Preprint; simplified detailed gearbox losses, NVH, and reliability.
[42] van den Hurk and Salazar (2021)	Structured-search core	Preprint / contextual; Energy-optimal design and control	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Ratio design; Efficiency; Optimization/control	Level D: Contextual	Preprint; simplified manufacturing, NVH, and durability constraints.
[43] Borsboom et al. (2022)	Structured-search core	Preprint / contextual; Analytical control and design optimization	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Ratio design; Efficiency; Optimization/control	Level D: Contextual	Simplified loss, NVH, and durability representation.
[44] Sanchez et al. (2024)	Structured-search core	Original peer-reviewed research; Transmission-error	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	NVH; Reliability/durability	Level B: Modeled/Optimized	Not EV-architecture specific; system-level

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
		analysis under wear and profile modification						gearbox selection not addressed.
[45] Palermo et al. (2018)	Structured-search core	Experimental measurement study; Transmission-error measurement method	General/not ratio-specific	General/component-level/not specified	Standalone gearbox/transmission	NVH; Experimental validation	Level A: Measured/Prototype	Focused on measurement/NVH indicator; limited architecture comparison.
[50] Konda et al. (2021)	Structured-search core	Preprint / contextual; Energy-optimal design/control with motor thermal constraints	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Ratio design; Efficiency; Thermal–lubrication; Optimization/control	Level D: Contextual	Motor thermal focus; gearbox thermal and lubrication models remain simplified.
[51] Beaudoin and Boulet (2021)	Structured-search core	Original peer-reviewed research; Dynamic analysis of gearshift limitations	Multi-speed	General/component-level/not specified	Standalone gearbox/transmission	Reliability/durability	Level B: Modeled/Optimized	Focused on shift quality; limited efficiency, durability, and architecture-wide comparison.
[52] Shi et al. (2023)	Structured-search core	Original peer-reviewed research; NVH/noise-reduction analysis	Two-speed	General/component-level/not specified	Standalone gearbox/transmission	NVH; Reliability/durability	Level B: Modeled/Optimized	Focused on one Two-speed transmission; limited broader architecture screening.
[54] Cianciotta et al. (2025)	Structured-search core	Original peer-reviewed research; Multi-objective gear optimization	General/not ratio-specific	Parallel-axis	Integrated EDU/e-axle	Efficiency; NVH; Thermal–lubrication; Reliability/durability; Optimization/control	Level B: Modeled/Optimized	Specific e-axle gear design; limited full drivetrain and experimental benchmarking.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
[57] Verbruggen et al. (2020)	Structured-search core	Original peer-reviewed research; Topology analysis and design	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Heavy-duty truck focus; limited gearbox component-level validation.
[58] Wellmann et al. (2019)	Structured-search core	SAE industry technical paper; Industry development / NVH integration study	General/not ratio-specific	General/component-level/not specified	Integrated EDU/e-axle	NVH; Thermal–lubrication	Level D: Contextual	Industry case focus; limited transparent architecture-screening methodology.
[59] Hermanova (2024)	Structured-search core	Original peer-reviewed research; Gear-ratio optimization	Single-speed; Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design	Level B: Modeled/Optimized	Motorcycle-specific; limited transferability to passenger or heavy-duty EV gearboxes.
[60] Sun et al. (2021)	Structured-search core	Original peer-reviewed research; Transmission-ratio optimization	Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Limited hardware validation and simplified NVH, lubrication, and reliability constraints.
[61] Kim et al. (2024)	Structured-search core	Original peer-reviewed research; Control-strategy and specification optimization	Two-speed	General/component-level/not specified	General/not integration-specific	Ratio design; Optimization/control	Level B: Modeled/Optimized	AWD architecture-specific; limited manufacturing and durability analysis.
[62] Hofman and Janssen (2017)	Structured-search core	Conference paper / optimization study; Integrated design optimization	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Limited hardware validation and simplified mechanical constraints.

Reference	Route	Source type / method	Ratio-count category	Gear-train topology	Integration level	Technical focus(es)	Evidence tag	Main limitation
[63] Morozov et al. (2019)	Structured-search core	SAE technical paper; Drivetrain analysis and optimization	Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Reliability/durability	Level B: Modeled/Optimized	Vehicle-class-specific; limited architecture generalization.
[64] Verbruggen et al. (2020)	Structured-search core	Conference paper / optimization study; Joint design and control optimization	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Powertrain-level focus; gearbox mechanical details simplified.
[66] Gear Solutions (2025)	Structured-search core	Technical magazine / contextual; Industry technical comparison	General/not ratio-specific	General/component-level/not specified	General/not integration-specific	NVH; Reliability/durability	Level D: Contextual	Not a peer-reviewed study; limited methodology and quantitative validation.
[68] Kwon et al. (2020)	Structured-search core	Original peer-reviewed research; Multi-objective optimization	Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Architecture-specific; limited experimental validation and mechanical durability constraints.
[69] He et al. (2023)	Structured-search core	Original peer-reviewed research; Performance comparison and adaptive shifting strategy	Two-speed	General/component-level/not specified	Standalone gearbox/transmission	Ratio design; Efficiency; Optimization/control	Level B: Modeled/Optimized	Limited detailed gearbox loss, NVH, and manufacturing analysis.

Note: Technical-focus coding is non-exclusive. Evidence tags use only the following terminology: Level A: Measured/Prototype; Level B: Modeled/Optimized; Level C: Limited Concept; and Level D: Contextual. The tags qualify the type of support available for a claim; they are not numerical effect weights, technology-maturity labels, or universal architecture rankings.

S3. Coding Rules for the Descriptive Evidence Map

Table S3. Coding rules used for the descriptive statistics in Figure 2 and the dimension-separated evidence counts in Table 5 of the main manuscript.

Field	Permitted categories	Assignment rule	Multiple assignment?
Search route	Structured-search core; targeted supplement	Structured-search core denotes the 40 records retained through the reported screening flow. Targeted supplement denotes refs. [16–27], retained after the gap audit.	No
Ratio count	Direct-drive; Single-speed; Two-speed; Multi-speed; General/not ratio-specific	Assign a category only when the source explicitly studies or compares the stated number of ratios. Direct-drive denotes no gearbox reduction stage. General/not ratio-specific is used when ratio count is not an explicit study variable.	Yes, when a source compares several ratio counts
Gear-train topology	Parallel-axis; Planetary; Compound planetary; Hybrid/other; General/component-level/not specified	Assign topology only when the mechanical gear-train arrangement is explicit. Planetary denotes a simple planetary set unless a compound arrangement is stated. Component studies without an architecture claim remain General/component-level/not specified.	Yes, for direct topology comparisons
Integration level	Standalone gearbox/transmission; Integrated EDU/e-axle; In-wheel/distributed drive; General/not integration-specific	Assign the physical integration boundary described in the source. No additional category, such as “Standalone axle/gearbox,” is used. General/not integration-specific is retained when the source does not define the integration boundary.	Yes, for explicit comparisons
Technical focus	Ratio design; Efficiency; NVH; Thermal–lubrication; Reliability/durability; Experimental validation; Optimization/control	Assign a focus only when it is a substantive method, result, or validation element rather than a passing mention. Multiple assignments are allowed and are counted non-exclusively.	Yes
Evidence tag	Level A: Measured/Prototype; Level B: Modeled/Optimized; Level C: Limited Concept; Level D: Contextual	Level A: measured, prototype, vehicle-level, or production-relevant evidence. Level B: peer-reviewed modeling or	No; strongest applicable tag is used

Field	Permitted categories	Assignment rule	Multiple assignment?
		optimization with realistic engineering assumptions. Level C: a simplified analytical or simulation concept with important omitted constraints. Level D: a review, preprint, standard, industry paper, or technical source used for context. The strongest applicable tag is assigned once per source.	
Ambiguity rule	General/not specified categories	Do not infer an architecture dimension from application context alone. Retain an explicit General/not specified category whenever ratio count, topology, or integration level is not stated.	Not applicable

S4. Detailed Time-Phased Research Roadmap

Table S4. Detailed time-phased future research roadmap for EV gearbox systems.

Time horizon	Main research direction	Concrete actions	Expected outcome
Near term	Better benchmarking; improved mechanical loss models; experimental validation; realistic drive-cycle evaluation; better shift-quality and drivetrain-efficiency comparisons. Add mission-specific passenger, commercial, and heavy-duty benchmarks.	Define common vehicle classes, motor maps, drive cycles, and cost assumptions; measure gearbox efficiency maps, gear mesh losses, bearing losses, churning losses, temperature rise, vibration, and acoustic response; compare Single-speed, Two-speed, Multi-speed, planetary, and e-axle candidates under the same assumptions. Use published ratios or ratings, mass, and duty cycles for two-speed passenger EVs, heavy-duty multi-speed vehicles, and integrated e-axles.	Shared benchmark cases; validated loss models; clearer criteria for when additional ratios or planetary layouts are justified; experimentally grounded architecture comparisons.
Medium term	Integrated efficiency-NVH-thermal optimization; reliability-aware gearbox design; improved e-fluids and lubrication systems; lightweight materials and	Develop co-optimization frameworks linking motor maps, gearbox losses, transmission error, housing dynamics, lubricant behavior, heat generation,	Multi-physics architecture-selection tools; reliability-aware optimization; integrated lubrication and cooling strategies; improved e-axle design methods; better

Time horizon	Main research direction	Concrete actions	Expected outcome
	manufacturing methods. Add sensor-ready e-axles and condition-monitoring hardware.	gear/bearing durability, manufacturing tolerances, and cost; evaluate controlled oil delivery, oil jets, e-fluids, lightweight housings, high-strength steels, coatings, and advanced surface finishing. Validate vibration, temperature, and lubricant sensing in fleet and high-utilization service.	link between manufacturing quality, NVH, and durability.
Long term	AI-assisted topology generation; digital twins; real-time health monitoring; self-optimizing e-axles; advanced compound planetary architectures; lifecycle-aware architecture selection.	Use AI and generative design to explore gearbox topology, ratio sets, planet configurations, housing/cooling layouts, and lubrication paths; connect digital twins with in-service sensing of vibration, temperature, lubricant condition, efficiency, and damage progression; develop adaptive control of cooling, lubrication, and shifting. Validate AI-generated and adaptive concepts against manufacturability, fail-safe operation, and hardware data.	Self-optimizing electric drive units; predictive maintenance; health-aware and lifecycle-aware e-axles; validated compound planetary drive units; architecture selection based on efficiency, NVH, thermal behavior, reliability, cost, and sustainability. Define mission-specific pathways for passenger, commercial, off-road, and distributed-drive platforms.

S5. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) Checklist

Completed for: A Design-Oriented Scoping Review of Electric-Vehicle Gearbox Technologies: Architectures, Gear-Ratio Selection, Efficiency, NVH, and Reliability

Note: Page references correspond to the submitted revised manuscript. Section, table, figure, and supplementary-table references are also provided because page numbering may change during production. The PRISMA-ScR flow applies to the 40-source structured-search core; the additional 12 sources are reported separately as a documented, gap-directed supplement rather than as a second complete PRISMA stream.

Table S5. Completed PRISMA-ScR checklist.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED IN THE MANUSCRIPT
TITLE			
Title	1	Identify the report as a scoping review.	p. 1 (Abstract explicitly identifies the work as a "design-oriented scoping review"); p. 3, Section 2.
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	p. 1, Abstract: background and scope; databases and screening counts; final 52-source set; descriptive synthesis; principal findings; limitations and research gaps.
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	pp. 1–3, Introduction and Section 1.1: existing evidence is fragmented across architecture, efficiency, NVH, thermal–lubrication, reliability, and design; the review maps these heterogeneous topics within one framework.
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	p. 2, Introduction: explicit central question on selecting an EV gearbox architecture for application-specific performance, efficiency, NVH, packaging, thermal, lubrication, reliability, manufacturability, and cost requirements; Section 1.1 lists five review outputs.
METHODS			

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED IN THE MANUSCRIPT
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	p. 3, Section 2: the review was not registered. No prospective or retrospective registration is claimed.
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	pp. 3–5, Sections 2.1–2.2 and Tables 1–2: 2010–2026, English language, source and publication types, EV/drivetrain scope, architecture relevance, technical focus, and explicit exclusion criteria.
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	pp. 3–5, Section 2.1 and Table 1: Scopus, IEEE Xplore, ScienceDirect, SpringerLink, and MDPI; final structured search executed 24 June 2026. Section 2.3 and Supplementary Table S1 describe the targeted supplement and citation chaining.
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	p. 4, Table 1: complete database-specific search strings, logical blocks, year limits, language scope, and initial record counts.
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	pp. 5–6, Section 2.3, Table 3, and Figure 1: identification, duplicate removal, title/abstract screening, full-text eligibility assessment, documented exclusion reasons, and subsequent gap-directed supplementation.
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	pp. 6–7, Section 2.4: standardized extraction template; predefined coding rules; source-level audit; ambiguous cases resolved from explicit source information or retained as general/not specified. A formal blinded parallel-coding exercise was not conducted.
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	p. 6, Section 2.4 lists all extracted fields. Supplementary Tables S2–S3 provide the complete source-level variables, coding categories, and definitions.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED IN THE MANUSCRIPT
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	Optional item. No formal risk-of-bias/critical-appraisal instrument was applied. A descriptive evidence-level rubric is reported in Section 2.5 and Table 4; source-level tags are provided in Supplementary Table S2.
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	pp. 7–8, Section 2.5, Figure 2, and Table 5; Supplementary Tables S2–S3. The review uses transparent descriptive counts, evidence-level composition, dimension-separated coding, and qualitative thematic synthesis. No pooled meta-analysis is claimed.
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	pp. 5–6, Section 2.3, Table 3, and Figure 1: 312 identified; 71 duplicates removed; 241 screened; 61 full texts assessed; 21 excluded with reasons; 40 structured-core sources; 12 targeted supplementary sources; 52 final sources.
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Section 2.5, Figure 2, and Table 5 summarize the evidence set. Supplementary Table S2 presents source-level characteristics, coding fields, limitations, and citations for all 52 sources.
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Optional item. No formal critical-appraisal results are reported. Descriptive evidence-level distributions are reported in Section 2.5, Table 4, Figure 2, and Supplementary Table S2.
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Sections 3–12 synthesize source-specific findings with citations. Supplementary Table S2 reports each source's type, architecture, method, technical focus, evidence level, principal contribution, and main limitation.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED IN THE MANUSCRIPT
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	Section 2.5; Sections 3–12; Figures 2–10; Tables 5–22; Supplementary Tables S2–S4: evidence profile, architecture comparisons, design implications, operational framework, illustrative screening, and research gaps/roadmap.
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Section 14, Conclusions, summarizes the evidence and application-specific architecture implications. Sections 13.1–13.2 link the evidence gaps to near-, medium-, and long-term priorities and to emerging technologies and industrial applications.
Limitations	20	Discuss the limitations of the scoping review process.	Section 13.3, Limitations of This Review: database/language limits; targeted-search traceability limits; study heterogeneity; evidence-strength variation; coding judgment; lack of formal inter-rater statistics; and broader application-scope limitations.
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Section 14, Conclusions, and Sections 13.1–13.2, Roadmap Synthesis and Emerging Technologies and Industrial Applications: interpretation of the architecture evidence, decision implications, and prioritized next research steps.
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	End matter, Funding: "This research received no external funding." Funding of the individual included sources was not charted as a review variable.

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews.

* Information sources are where evidence is identified, such as bibliographic databases, social-media platforms, and websites.

† "Sources of evidence" is an inclusive term covering the different types of evidence or data sources eligible in a scoping review.

‡ Data extraction in a scoping review is commonly termed data charting.

§ Critical appraisal means systematically examining evidence validity, results, and relevance. Items 12 and 16 are optional in PRISMA-ScR.

Checklist source: [74] Tricco, A.C.; Lillie, E.; Zarin, W.; O'Brien, K.K.; Colquhoun, H.; Levac, D.; Moher, D.; Peters, M.D.J.; Horsley, T.; Weeks, L.; Hempel, S.; et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann. Intern. Med. 2018, 169, 467–473. https://doi.org/10.7326/M18-0850.