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A review of cell-to-body (CTB) battery-structure integration design for electric vehicles

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The automotive industry is undergoing a profound transformation toward electrification, with battery electric vehicles (BEVs) emerging as the dominant solution for sustainable transportation. Among the critical innovations driving this transition, Cell-to-Body (CTB) technology represents a paradigm shift in battery system architecture, fundamentally redefining the relationship between energy storage and vehicle structure. This review examines the structural design principles, mechanical performance characteristics, and engineering challenges associated with CTB integration. By analyzing recent developments from industry leaders including BYD's Blade Battery CTB system and Tesla's structural battery pack, this paper provides a comprehensive overview of the technological evolution from conventional Cell-to-Module (CTM) configurations toward full structural integration. The discussion encompasses topology optimization strategies, crash-worthiness considerations, thermal management integration, and manufacturing implications. Furthermore, this review identifies critical research gaps and future directions for advancing CTB technology in next-generation electric vehicles.

KEYWORDS
cell-to-body, cell-to-module, cell-to-module-to-pack, crash-worthiness, New energy vehicles

1 Introduction

The global automotive landscape is experiencing unprecedented change as electrification accelerates to address climate change and energy security concerns (Belingardi and Scattina, 2023). Battery electric vehicles have transitioned from niche products to mainstream transportation solutions, with global sales exceeding 10 million units annually (IEA, 2023). However, the integration of large-scale battery systems into vehicle architectures presents significant engineering challenges related to packaging efficiency, structural integrity, weight optimization, and safety performance (Acar et al., 2024).

Traditional electric vehicle architectures have employed a modular approach wherein battery cells are assembled into modules, which are subsequently integrated into packs mounted beneath the vehicle floor or within dedicated compartments. This Cell-to-Module-to-Pack (CTMP) configuration, while providing manufacturing flexibility and service accessibility, introduces substantial structural redundancy and packaging inefficiencies. The battery pack functions merely as an energy storage device, requiring separate structural elements to support mechanical loads and protect against crash impacts (Kianirad,

2021).The emergence of Cell-to-Pack (CTP) technology marked the first significant departure from conventional modular architectures by eliminating intermediate module structures and directly integrating cells into the pack enclosure (Shen et al., 2022). This innovation improved volume utilization by 15%–20% and reduced component count substantially (Wang et al., 2021). Building upon CTP principles, Cell-to-Body (CTB) and Cell-to-Chassis (CTC) technologies represent the next evolutionary step, wherein the battery system becomes an integral load-bearing component of the vehicle structure itself (Lian et al., 2023).

BYD Auto's introduction of CTB technology in 2022, implemented in the Seal sedan utilizing Blade Battery technology, demonstrated the commercial viability of moderate structural integration (Yu, 2022). This approach achieves torsional stiffness exceeding 40,000 Nm/degree—approximately 70% improvement over conventional architectures—while retaining modular serviceability through the elongated prismatic cell geometry (Lian et al., 2023). In contrast, Tesla's structural battery pack employing 4680 cylindrical cells in the Model Y established a radically different approach, eliminating the floor pan entirely and bonding cells directly to front and rear cast aluminum subframes (Ank et al., 2023). These divergent philosophies—BYD's "integration with boundaries" versus Tesla's "integration without compromise"—reflect fundamentally different assessments of the trade-offs between structural efficiency and lifecycle serviceability. While both manufacturers claim 10%–15% mass reduction and significant stiffness improvements, the divergence in repair complexity and economic viability remains insufficiently quantified. These developments have catalyzed extensive research into the structural, thermal, and safety implications of battery-structure integration.

This review provides a systematic examination of CTB structural design principles, analyzing the technological foundations, engineering methodologies, performance characteristics, and future research directions. The scope encompasses structural topology optimization, materials selection, crash-worthiness design, manufacturing processes, and the trade-offs inherent in deep integration strategies.

2 Evolution of battery system architectures

2.1 From conventional modular systems to integrated designs

The architectural evolution of electric vehicle battery systems reflects a continuous drive toward higher integration levels and improved system efficiency. Conventional Cell-to-Module (CTM) architectures, exemplified by early Nissan Leaf and Chevrolet Bolt designs, organize individual cells into modules containing 12-24 cells each, with multiple modules assembled into a complete pack (Gorsch et al., 2025). This approach facilitates manufacturing scalability and enables module-level replacement for service operations. However, the proliferation of structural components—including module housings, interconnects, and mounting hardware—reduces gravimetric and volumetric energy density while adding unnecessary mass (Baazouzi et al., 2023).

Cell-to-Pack (CTP) technology, pioneered by CATL and subsequently adopted by numerous manufacturers, eliminates modular substructures by directly integrating cells into the pack enclosure (Jin et al., 2022). This architectural simplification reduces parts count by approximately 40% and improves volume utilization efficiency to 60%–70%, compared to 40%–50% for conventional CTM systems (Wang et al., 2021). The thermal management system in CTP configurations must accommodate direct cell-to-coolant or cell-to-heat-spreader interfaces, necessitating advanced cooling strategies such as liquid cold plates or immersion cooling (Sun et al., 2022).

The progression from CTP to CTB/CTC represents a fundamental re conceptualization of the battery system's structural role. Rather than treating the battery pack as a payload supported by the vehicle chassis, CTB integration positions the battery as a primary structural member contributing to global vehicle stiffness and crash energy management (Awan et al., 2026). This functional integration demands sophisticated engineering approaches to address the competing requirements of electrochemical performance, mechanical integrity, and manufacturing feasibility (Allgäuer et al., 2025).

2.2 Structural integration concepts and definitions

The terminology surrounding advanced battery integration remains somewhat inconsistent across literature and industry practice. Cell-to-Chassis (CTC) generally refers to configurations where the battery pack structure is directly integrated with the vehicle chassis or frame, often utilizing the battery enclosure as a floor panel or structural cross-member (Belingardi and Scattina, 2023). Cell-to-Body (CTB), as implemented by BYD, specifically denotes integration with the vehicle body-in-white (BIW), wherein the battery pack upper cover serves as the vehicle floor panel, and the battery structure contributes to body stiffness and crash-worthiness (Lian et al., 2023).

Tesla's structural battery pack represents a distinct approach wherein the battery pack itself constitutes a structural element bonded to the front and rear cast aluminum subframes, effectively creating a unified structural sandwich (Ank et al., 2023). This configuration eliminates the traditional floor pan entirely, with the battery pack enclosure serving as the primary floor structure. The 4680 cylindrical cells within this architecture contribute to structural performance through their arrangement in a honeycomb-like pattern, providing load paths for vertical and lateral forces (Hasan et al., 2023).

Figure 1 show Ctb technology system: from architecture implementation. Figures (a–f) present a comprehensive visual analysis of CTB technology across structural, material, and safety dimensions. Figure (a) establishes the architectural evolution from CTM to CTC; Figure (b)compares competing implementation philosophies; Figure (c) explains load-bearing mechanisms; Figure (d) identifies material optimization constraints; Figure (e) characterizes thermal runaway dynamics; and Figure (f) maps multi-physics stress distributions critical for durability design (Huang et al., 2026).

The distinction between these approaches carries significant implications for manufacturing processes, repair procedures, and

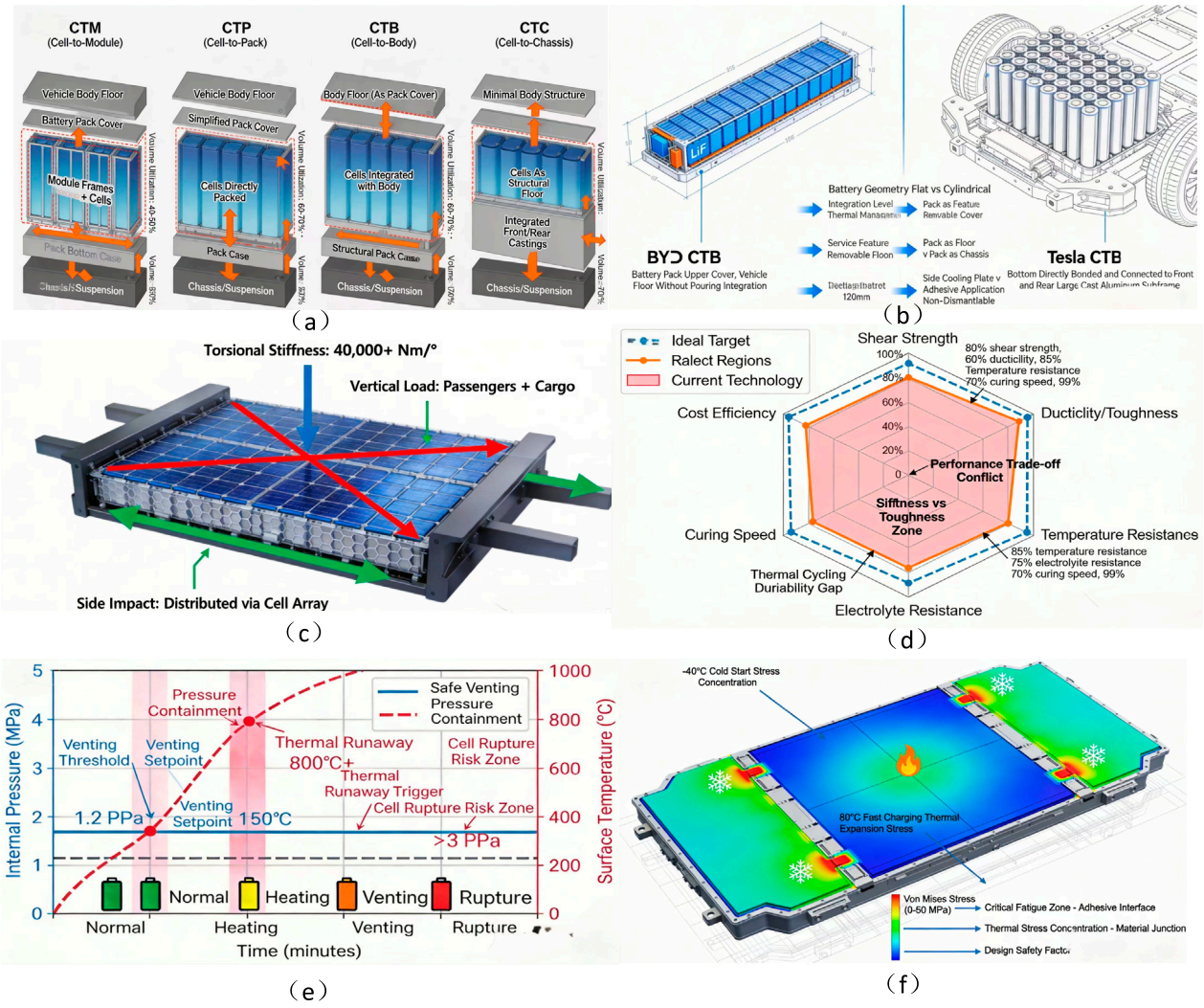


FIGURE 1
Ctb technology system: from architecture to implementation.

vehicle lifecycle management. Full structural integration typically requires adhesive bonding between the battery pack and vehicle structure, creating essentially permanent connections that complicate battery replacement or recycling operations (Krüger et al., 2022). Conversely, semi-integrated designs maintain bolted connections that preserve serviceability while achieving partial structural benefits.

2.3 Comparative analysis of integration philosophies

The concurrent development of BYD CTB and Tesla CTC provides a natural experiment in engineering trade-off optimization. Analysis of published technical data reveals distinct optimization strategies with different risk profiles.

BYD's CTB represents "bounded integration." The Blade Battery's prismatic cells—900+ mm length with high aspect ratio—provide favorable geometry for unidirectional load bearing in longitudinal compression, contributing to the reported 40,000+ Nm/degree torsional stiffness (Lian et al., 2023). Volume utilization of approximately 66% (implied by Wang et al., 's 2021 CTP data and Gorsch et al., 's 2025 teardown analysis) is achieved without sacrificing modular serviceability. The LFP chemistry provides intrinsic thermal stability, reducing reliance on complex thermal management for safety assurance (Yu, 2022). This architecture accepts modest efficiency gains in exchange for retained compatibility with existing service infrastructure and lower insurance risk.

Tesla's CTC embodies "unconstrained integration." The 4680 cylindrical cells—80 mm diameter with omnidirectional stiffness—are arranged in honeycomb patterns and bonded to cast aluminum subframes, eliminating 70+ parts from the floor structure (Ank et al., 2023). Volume utilization exceeds 70%, and the unified structural sandwich achieves comparable torsional stiffness improvements. However, this efficiency is purchased through extreme interdependence: cell replacement is impossible without body-in-white separation, and thermal management relies on structural adhesive as thermal interface material (Ank et al.,

2023). The NCM chemistry's higher energy density is accompanied by greater thermal runaway risk, necessitating sophisticated venting and cooling systems that add complexity and potential failure modes.

The critical insight is that "CTB" and "CTC" are not merely terminological variants but represent distinct points on a spectrum of integration aggressiveness. BYD's approach optimizes within constraints of serviceability, safety margins, and ecosystem compatibility; Tesla's approach maximizes performance metrics contingent upon market acceptance of non-repairability and insurance ecosystem adaptation. This divergence suggests that optimal integration level varies by market segment—commercial fleets prioritizing uptime and repairability may prefer CTB's bounded integration, while performance-oriented consumer markets may accept CTC's risks for manufacturing efficiency and handling precision.

A significant gap in current literature is the absence of quantitative lifecycle cost analysis comparing these architectures. While stiffness and mass metrics are published, data on repair frequency, insurance cost differentials, residual value retention, and end-of-life processing costs remain proprietary or unreported, impeding objective assessment of net value proposition.

3 Structural design principles and topology optimization

3.1 Load path integration and force distribution

The fundamental challenge in CTB structural design involves optimizing load paths to effectively utilize the battery system's structural capacity while protecting electrochemical components from mechanical damage. The battery pack in CTB configurations must simultaneously satisfy three primary structural functions: supporting vertical loads from passenger and cargo weight, resisting torsional loads during vehicle maneuvering, and managing crash energy during frontal, side, and rear impacts (Zhang et al., 2021).

Topology optimization techniques have emerged as essential tools for CTB structural design, enabling engineers to distribute material efficiently within the constrained packaging space defined by cell arrangements and thermal management requirements (Roper and Kim, 2023). Multi-objective optimization frameworks must balance competing objectives including stiffness-to-weight ratio, crash energy absorption, manufacturing cost, and thermal performance (Lian et al., 2025).

The integration of battery cells into structural load paths requires careful consideration of cell mechanical properties. Lithium-ion cells exhibit anisotropic mechanical behavior, with significantly higher stiffness and strength along the cell axis compared to radial directions (Singh et al., 2025). Prismatic cells, such as BYD's Blade Battery, offer favorable geometry for longitudinal load bearing due to their elongated form factor and high aspect ratio (Yu, 2022). Cylindrical cells, exemplified by Tesla's 4680 format, provide omnidirectional stiffness through their circular cross-section but require careful arrangement to ensure continuous load paths (Baazouzi et al., 2023).

3.2 Multi-material design strategies

CTB structures inherently require multi-material approaches to address the diverse functional requirements of structural performance, electrical isolation, thermal management, and corrosion resistance. High-strength steel grades remain predominant for battery enclosures due to their excellent specific strength, formability, and cost-effectiveness (Chen et al., 2022). Advanced high-strength steels (AHSS) with tensile strengths exceeding 1000 MPa enable thin-wall designs that minimize weight while providing adequate crash protection.

Aluminum alloys, particularly 6xxx series extrusions and castings, find extensive application in CTB structures where weight reduction priorities justify higher material costs (Chen et al., 2022). The front and rear cast aluminum subframes in Tesla's structural battery pack exemplify the integration of large-scale castings to reduce part count and assembly complexity. Aluminum honeycomb or foam structures between cells can provide multifunctional benefits including crash energy absorption, thermal insulation, and electrical isolation (Mudassir et al., 2020).

Composite materials, including carbon fiber reinforced polymers (CFRP) and glass fiber reinforced polymers (GFRP), offer exceptional specific stiffness and strength but face challenges related to cost, electrical conductivity, and repairability in CTB applications (Dabasa et al., 2025). Current production CTB systems predominantly utilize metallic architectures, with composite applications limited to non-structural covers or thermal management components (Mei et al., 2025).

3.3 Joining and connection technologies

The structural integrity of CTB systems depends critically on joining technologies that must accommodate multi-material interfaces, electrical isolation requirements, and manufacturing tolerances. Advanced adhesive bonding has emerged as the primary joining method for CTB integration, providing continuous load distribution, sealing against environmental ingress, and galvanic corrosion isolation between dissimilar metals (Krüger et al., 2022).

Structural adhesives for CTB applications must satisfy demanding requirements including high shear and peel strength, durability under thermal cycling (−40 °C–80 °C typical) (IEC, 2018), resistance to electrolyte and automotive fluids, and compatibility with automated dispensing processes. Epoxy-based structural adhesives with toughening modifiers dominate current applications, offering lap shear strengths exceeding 20 MPa on properly prepared aluminum and steel substrates (Lian et al., 2023).

Mechanical fastening retains importance for serviceable connections and as redundant load paths in critical safety applications. Self-piercing rivets (SPR) and flow-drill screws (FDS) enable single-sided joining of overlapping sheet materials without pre-drilling, facilitating automation and reducing assembly time (Asirvatham et al., 2026). The combination of adhesive bonding with mechanical fastening provides optimal performance through adhesive peeling resistance and mechanical overload protection.

4 Crashworthiness and safety design

4.1 Frontal and rear impact protection

The integration of battery systems into vehicle primary structure fundamentally alters crash energy management strategies. In conventional architectures, the battery pack is typically positioned between the front and rear crush zones, protected by dedicated structural elements designed to absorb impact energy before intrusion reaches the battery enclosure (Victor Chombo et al., 2021). CTB configurations must distribute crash energy through the battery structure itself while preventing cell damage that could trigger thermal runaway.

Frontal crash-worthiness design for CTB vehicles emphasizes the creation of efficient load paths that bypass the battery pack or transmit forces through specifically engineered structural elements. The front subframe and longitudinal members must manage crash energy through controlled deformation modes, preventing excessive deceleration pulses that could compromise cell integrity (Navale et al., 2021). The transition from front structure to battery enclosure requires careful engineering to avoid force concentrations that could cause localized cell compression or shear.

Tesla's structural battery pack addresses frontal impact protection through the integration of cast aluminum crash rails that attach directly to the battery pack front edge, creating a continuous load path from the front bumper to the passenger compartment (Ank et al., 2023). BYD's CTB implementation utilizes the Blade Battery cells themselves as structural elements within the floor pan, with the elongated cell geometry providing inherent resistance to longitudinal compression (Lian et al., 2023).

4.2 Side impact resistance

Side impacts present particular challenges for CTB designs due to the limited crush space available between the impacting object and the passenger compartment. The battery pack's position along the vehicle floor places it directly in the load path of side pole and barrier impacts, necessitating robust structural protection (Arslan and Karamangil, 2025). Conventional vehicles utilize rocker panels and side rails to distribute side impact forces, but CTB integration requires the battery structure to participate actively in load bearing.

Advanced CTB designs incorporate high-strength steel or aluminum extrusions along the battery perimeter to create protective cage structures (Krüger et al., 2022). The integration of the battery side frame with the vehicle rocker panel, as implemented in several production designs, eliminates structural redundancy while improving side intrusion resistance. Cellular structures, including aluminum honeycomb or engineered lattice configurations, can be integrated between the battery enclosure and outer body panels to provide energy absorption without excessive weight penalty (Scurtu et al., 2023).

Computational modeling and physical testing demonstrate that properly designed CTB structures can achieve equivalent or superior side impact performance compared to conventional architectures while reducing overall vehicle mass (Muresanu et al., 2024). The key design parameter involves balancing the stiffness of the battery enclosure to resist intrusion against the need for controlled deformation to manage deceleration pulses (Wang et al., 2021).

4.3 Thermal runaway prevention and containment

Structural design for CTB systems must incorporate strategies to prevent and mitigate thermal runaway propagation between cells. The close packing of cells in integrated architectures reduces the barriers between adjacent cells compared to modular designs, potentially facilitating heat transfer during failure events (Jin et al., 2022). Engineering solutions include the incorporation of aerogel or ceramic fiber insulation between cells, engineered venting pathways to direct hot gases away from occupied spaces, and structural fuses that isolate cell groups during thermal events.

The mechanical behavior of cells during thermal runaway creates additional structural considerations. Internal pressure buildup can result in cell venting or rupture, generating forces that must be accommodated by the enclosure structure without compromising integrity (Yeganehdoust et al., 2025). CTB designs must provide adequate venting area and pressure relief mechanisms while maintaining structural performance under normal operating conditions.

5 Thermal-structural integration

5.1 Cooling system integration

The elimination of modular structures in CTB architectures fundamentally changes thermal management system design. Direct cell-to-coolant interfaces become essential, as the intermediate module housings that previously provided thermal buffering are removed (Shen et al., 2022). Liquid cooling systems utilizing cold plates, cooling channels integrated into the battery enclosure, or immersion cooling must be designed to maintain cell temperature uniformity while contributing to structural performance.

Structural adhesives used in CTB bonding must demonstrate thermal conductivity compatible with heat dissipation requirements, or thermal interface materials must be incorporated at critical junctions (Zhang et al., 2024). The thermal expansion mismatch between metallic enclosures, cells, and cooling components creates mechanical stresses that must be managed through compliant interface designs or flexible connections.

Advanced cooling concepts for CTB include phase change materials (PCM) integrated into cell gaps to provide thermal buffering during fast charging, and heat pipe systems that transport heat from cell centers to peripheral cooling surfaces (Lee et al., 2025). These thermal management elements must be structurally integrated without compromising the primary load-bearing functions of the battery system.

5.2 Thermal-mechanical coupling effects

The strong coupling between thermal and mechanical behavior in CTB systems necessitates multi-physics design approaches. Temperature variations induce thermal stresses in the integrated structure due to differential expansion coefficients between materials (Giusti et al., 2025). Extreme temperature conditions, including cold start at −40 °C and fast charging at elevated

temperatures, create stress cycles that can compromise adhesive bonds or fatigue-sensitive components.

Finite element analysis frameworks for CTB design must incorporate coupled thermal-mechanical solvers to predict stress distributions under combined thermal and mechanical loading (Singh et al., 2025). Experimental validation requires environmental chambers capable of reproducing thermal cycles while applying mechanical loads representative of driving conditions.

6 Manufacturing and assembly considerations

6.1 Assembly sequence and integration

CTB manufacturing fundamentally alters vehicle assembly sequences compared to conventional architectures. The battery pack, rather than being installed as a subassembly beneath the completed body, becomes integrated early in the assembly process, often serving as the foundation upon which front and rear structures are built (Lian et al., 2023). This approach, termed "unboxed process" by Tesla, reduces assembly line length and capital investment while improving structural precision through integral fixturing.

Precision requirements for CTB assembly are substantially higher than for conventional battery mounting, as dimensional variations directly affect vehicle geometry and suspension alignment. Adhesive bonding processes require controlled environmental conditions, surface preparation, and cure monitoring to ensure consistent joint quality (Krüger et al., 2022). The structural adhesives typically require elevated temperature curing, necessitating integration of heating systems into assembly fixtures or post-assembly oven processes.

6.2 Quality control and inspection

Non-destructive evaluation methods for CTB structures must address the inspection of bonded joints, cell integrity, and dimensional accuracy without disassembly. Ultrasonic testing, thermography, and X-ray computed tomography provide capabilities for bond line inspection and internal defect detection (Barathi Raja, 2025). In-process monitoring of adhesive dispensing and curing parameters enables statistical process control to maintain quality consistency.

The permanent nature of structural bonding in CTB designs complicates repair and service operations compared to bolted connections. Manufacturer repair procedures must address scenarios including adhesive joint failure, cell replacement, and collision damage, often requiring specialized equipment and training (Belingardi and Scattina, 2023).

7 Performance characteristics and comparative analysis

7.1 Stiffness and dynamics

Field data and laboratory testing demonstrate that CTB integration provides substantial improvements in vehicle torsional stiffness, a key parameter influencing handling precision, NVH performance, and durability. BYD reports that the Seal sedan achieves torsional stiffness exceeding 40,000 Nm/degree through CTB implementation, representing approximately 70% improvement over comparable conventional architectures (Lian et al., 2023). This stiffness enhancement enables suspension tuning for improved ride comfort without compromising handling response.

The mass reduction achieved through CTB integration, typically 10%–15% of battery system weight, contributes to improved energy efficiency and vehicle dynamics (Awan et al., 2026). The lowering of the vehicle center of gravity through floor-integrated battery placement, combined with the increased body stiffness, reduces roll during cornering and improves transient response.

7.2 Durability and fatigue

Long-term durability of CTB structures depends on the fatigue performance of adhesive joints, cell-to-structure interfaces, and metallic components under combined thermal and mechanical cycling. Accelerated testing protocols must replicate the accumulated damage from road-induced vibrations, thermal cycling, and occasional overload events over the vehicle design life (typically 15 years/240,000 km) (ISO, 2006).Initial field data from vehicles with CTB technology indicates satisfactory durability performance, though long-term validation remains ongoing. The elimination of bolted connections removes potential wear and loosening mechanisms, but adhesive degradation under sustained load and environmental exposure requires monitoring (Belingardi and Scattina, 2023).

7.3 Economic and ecosystem implications

The technical performance advantages of CTB/CTC architectures must be evaluated within broader economic and industrial ecosystems that determine commercial viability.

Manufacturing and Supply Chain Restructuring. CTB/CTC technologies accelerate vertical integration trends. BYD's in-house Blade Battery production and Tesla's 4680 cell manufacturing reflect strategic positioning to capture value from "battery-as-structure" integration. This vertical integration reduces parts count by approximately 40% and improves volume utilization to 60%–70% compared to 40%–50% for conventional CTM systems (Wang et al., 2021), but threatens independent battery suppliers with marginalization unless they develop comparable chassis-integration capabilities. The industry may bifurcate between integrated OEMs and modular suppliers serving repairability-focused segments.

Service Infrastructure and Repair Economics. The permanent bonding characteristic of current CTB designs—requiring lap shear strengths exceeding 20 MPa and durability under thermal cycling** (Lian et al., 2023; Krüger et al., 2022)—complicates repair and service operations. Unlike conventional bolted connections, adhesive joints cannot be non-destructively disassembled, potentially converting minor underbody impacts into total loss scenarios. This risk transfer—from manufacturing efficiency to insurance and residual value—may limit CTC adoption in commercial vehicle segments despite superior technical specifications, while CTB's retained modularity may prove

essential for fleet applications where downtime costs exceed energy efficiency gains.

End-of-Life and Circular Economy Considerations. As CTB-equipped vehicles approach end-of-life, sustainable disassembly and recycling processes must be developed. The permanent bonding characteristic complicates battery removal for recycling or second-life applications. Research into reversible adhesive systems or designed debonding processes could address these concerns while maintaining structural benefits (Awan et al., 2026). However, current designs prioritize manufacturing efficiency over end-of-life recoverability, potentially conflicting with emerging battery passport regulations requiring material traceability and recycling accountability.

These ecosystem implications suggest that CTB/CTC adoption will be segment-specific rather than universal. The "bounded integration" of BYD CTB may dominate commercial and mass-market segments where total cost of ownership and serviceability predominate, while Tesla's "unconstrained integration" may be confined to premium consumer segments where performance metrics and manufacturing efficiency justify acceptance of non-repairability risks (Zhao et al., 2025).

8 Future directions and research opportunities

8.1 Advanced materials and manufacturing

Future CTB developments will likely incorporate advanced materials including high-strength aluminum alloys, carbon fiber composites, and functional materials with integrated sensing capabilities. Additive manufacturing enables topology-optimized structures with complex internal geometries that improve crash energy absorption while reducing weight (Dabasa et al., 2025). The integration of smart materials providing self-healing, damage sensing, or adaptive stiffness characteristics offers potential for next-generation CTB systems.

8.2 Solid-state battery integration

The transition to solid-state batteries (SSBs) presents both opportunities and challenges for CTB architectures. Solid-state cells offer improved mechanical robustness and thermal stability compared to conventional lithium-ion cells, potentially enabling more aggressive structural integration (Guo et al., 2025). Specifically, the elimination of flammable liquid electrolyte reduces thermal runaway severity, potentially permitting reduced structural containment and additional mass savings beyond current 10%–15% achievements (Awan et al., 2026). The higher mechanical stiffness of ceramic solid electrolytes could enable cells to bear primary structural loads, realizing the "structural battery" concept where energy storage and load bearing are truly unified rather than merely co-located.

However, the manufacturing processes and interface requirements for SSBs differ substantially, necessitating CTB redesign to accommodate solid electrolyte constraints and stacking architectures. Critical incompatibilities include: (1) Interface impedance sensitivity—SSBs require sustained stack pressure to maintain solid-solid electrolyte-electrode contact, but CTB's adhesive bonding and thermal cycling-induced deformation may compromise this pressure; (2) Brittleness and damage tolerance—ceramic electrolytes are vulnerable to fracture under impact loads that CTB architectures must accommodate; (3) Manufacturing scale—current SSB production utilizes batch processes incompatible with CTB's continuous assembly line requirements.

Technology readiness assessments suggest that SSB-CTB integration remains 5–10 years from commercial viability. Current CTB designs must optimize around liquid electrolyte constraints—particularly the 60%–70% volume utilization and thermal cycling durability from −40 °C to 80 °C (Wang et al., 2021; Lian et al., 2023)—without assuming SSB retrofit compatibility. The "opportunity" of SSBs for CTB is thus prospective rather than immediate; near-term research should prioritize resolution of adhesive durability, repairability, and thermal-mechanical coupling in current lithium-ion-based architectures."

8.3 End-of-life considerations

As CTB-equipped vehicles approach end-of-life in increasing numbers, sustainable disassembly and recycling processes must be developed. The 10%–15% mass reduction and 40% parts count reduction achieved through CTB integration (Wang et al., 2021; Awan et al., 2026)—while beneficial for manufacturing efficiency and driving performance—create end-of-life complications. The permanent bonding characteristic complicates battery removal for recycling or second-life applications; adhesive joints designed for 20+ MPa shear strength and 15-year durability are inherently resistant to non-destructive disassembly.

Research into reversible adhesive systems, designed debonding processes, or modular CTB variants could address these concerns while maintaining structural benefits (Awan et al., 2026). However, these solutions impose trade-offs: reversible adhesives may compromise joint durability under thermal cycling; designed debonding features reduce structural efficiency; modular variants approach conventional CTP architectures, negating integration benefits. The optimization of CTB architectures for both structural performance and end-of-life recoverability remains unresolved.

From a systems perspective, the 60%–70% volume utilization and manufacturing efficiency gains must be weighed against potential reductions in material recovery rates. Current recycling infrastructure assumes pack-level dismantling; CTB architectures with permanent cell-to-structure bonding may require destructive shredding followed by metallurgical separation, reducing recovered material purity and value. This "design for recycling" gap may conflict with emerging regulations requiring high material recovery rates and full lifecycle carbon accounting.

The divergence between BYD CTB and Tesla CTC becomes relevant here: BYD's retained modularity may prove more adaptable to evolving recycling requirements, while Tesla's extreme integration may face higher end-of-life compliance costs. This regulatory risk adds uncertainty to long-term value assessments of CTC architectures.

9 Conclusion

Cell-to-Body technology represents a transformative advancement in electric vehicle architecture, fundamentally

redefining the structural role of battery systems. Through the integration of energy storage and load-bearing functions, CTB designs achieve significant improvements in packaging efficiency, vehicle stiffness, and weight reduction compared to conventional modular approaches. The successful commercial implementation by BYD, Tesla, and other manufacturers demonstrates the technical feasibility and market viability of structural battery integration.

This review has focused primarily on BYD CTB and Tesla CTC as the first large-scale commercial implementations of battery-structure integration. While these cases represent distinct technical philosophies—bounded versus radical integration—and collectively dominated 2023 global BEV sales, we acknowledge that this scope limits comprehensive geographic and technological coverage. The emerging CTP 3.0 (CATL), Unified Cell (Volkswagen), and E-GMP (Hyundai) platforms, among others, warrant future analysis as their technical data mature.

The engineering challenges associated with CTB—encompassing structural optimization, crash-worthiness, thermal management, and manufacturing—have driven innovation in multi-material design, advanced joining technologies, and integrated simulation methodologies. Continued research addressing long-term durability, repair-ability, and end-of-life considerations will be essential for widespread adoption.

As the automotive industry progresses toward higher levels of electrification and autonomous operation, CTB and related integration technologies will likely become standard architecture rather than premium features. The convergence of structural, electrical, and thermal functions in the battery system exemplifies the system-level thinking required for sustainable transportation solutions. Future developments in solid-state batteries, advanced manufacturing, and smart materials will further expand the possibilities for structural integration, potentially enabling vehicle architectures that are currently impractical with conventional approaches.

The transition to CTB represents more than an incremental improvement in battery packaging; it constitutes a fundamental re-conceptualization of vehicle structure that will influence automotive design for decades to come. As research continues to address the technical challenges and optimize the trade-offs inherent in deep integration, CTB technology will play a central role in enabling the next-generation of efficient, safe, and sustainable electric vehicles.

Author contributions

YL: Data curation, Conceptualization, Writing – original draft. ZY: Investigation, Writing – original draft, Methodology. XH: Supervision, Writing – review and editing, Software. JT: Writing – review and editing, Funding acquisition, Formal Analysis.

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XH was employed by China Machinery Huanyu (Shan Dong) Vehicle Certification And Testing Co., Ltd.

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